U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-270 001

Field Testing of Emission Controls for Asbestos Manufacturing Waste Piles

IIT Research Inst, Chicago, Ill

Prepared for

Industrial Environmental Research Lab, Cincinnati, Ohio

May 77

PB 270 081

EPA-600/2-77-081
May 1977

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related areas. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-098	2.
3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE: Field Testing of Emission Controls for Asbestos Manufacturing Waste Piles	5. REPORT DATE: May 1977 issuing date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): Colin F. Harwood, Paul K. Ase	8. PERFORMING ORGANIZATION REPORT NO. C6138 - 15
9. PERFORMING ORGANIZATION NAME AND ADDRESS: IIT Research Institute, 10 West 35th Street, Chicago, Ill. 60616	10. PROGRAM ELEMENT NO. 1AB604
	11. CONTRACT/GRANT NO. 68-02-1872
12. SPONSORING AGENCY NAME AND ADDRESS: Industrial Environmental Research Laboratory - Cin., OH, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED: Final
	14. SPONSORING AGENCY CODE: EPA/600/12
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

Abatement of fugitive emissions from asbestos cement waste disposal activities has been studied. The primary sources of asbestos emissions are, (1) transfer of baghouse fines to the dump, (2) crushing and leveling of waste on the fines, (3) active dump areas, (4) inactive dump areas. The emission control options used in other industries were reviewed. Those applicable to asbestos cement waste were analyzed for cost effectiveness using engineering estimation techniques applied to a model typical plant. It was estimated that bagging of the fine waste would reduce dumping emissions by 80%, while a soil-vegetative cover would reduce the long-term emissions by 90%. Application of the three control options would reduce the emissions by 87% at a total annual cost of $17,850 for the model typical plant. Field testing of the control options indicated that the assumptions made were reasonable and that the emissions were in line with those predicted. Background asbestos levels in the ambient air were found to be high and to exist both upwind and downwind of the plant for considerable distances (10 km). Emissions from small test plots were too low to be measured but the stability of the chemically stabilized and the soil-vegetated covers were excellent. Despite the high alkalinity of asbestos waste (pH 12), vegetation was grown on the soil to give a 95% cover, far in excess of the coverage required to prevent soil erosion.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Asbestos Cement Products Fibers Disposal Field Tests	Air Pollution Control Open Sources Asbestos Fibers Asbestos Cement Waste Chemical Binder Vegetative Cover	13B

18. DISTRIBUTION STATEMENT: Release to Public	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 149
	20. SECURITY CLASS (This page): Unclassified	22. PRICE: PC A07 MF A01

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977-757-056/6506 Region No. 5-11

EPA-600/2-77-098
May 1977

FIELD TESTING OF EMISSION CONTROLS FOR ASBESTOS MANUFACTURING WASTE PILES

by

Colin F. Harwood
Paul K. Ase
IIT Research Institute
Chicago, Illinois 60616

Contract No. 68-02-1872

Project Officer

Mary K. Stinson
Industrial Pollution Control Division
Industrial Environmental Research Laboratory
Edison, New Jersey 08817

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

These studies were undertaken to perform field testing of control technology to abate emissions from asbestos cement waste disposal activities. Effectiveness of the selected control options has been evaluated and a total annual cost of applying these controls to a model typical plant has been estimated.

Such information will be of value to EPA's enforcement program (Office of Air Quality Planning and Standards) and to the Office of Toxic Substances. Within EPA's RAD program the information will be used in the Industrial Program, IERL-Ci, and in the Health Effects Laboratory, IERL-RTP. Other groups active in studies with asbestos such as NIEHS, NIOSH, OSHA, Bureau of Mines, Mining Enforcement and Safety Administration, and Department of Transportation will also use this report. Other users of the report will be asbestos mining, milling, and manufacturing industries as well as other mineral industries where asbestos is a contaminant.

For further information concerning this subject the Industrial Pollution Control Division should be contacted.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Abatement of fugitive emissions from asbestos cement waste disposal activities has been studied. The primary sources of asbestos emissions are, (1) transfer of baghouse fines to the dump, (2) crushing and leveling of waste on the fines, (3) active dump areas, (4) inactive dump areas. The emission control options used in other industries were reviewed. Those applicable to asbestos cement waste were analysed for cost effectiveness using engineering estimation techniques applied to a model typical plant. It was estimated that bagging of the fine waste would reduce dumping emissions by 80%, while a soil-vegetative cover would reduce the long-term emissions by 90%. Application of the three control options would reduce the emissions by 87% at a total annual cost of $17,850 for the model typical plant. Field testing of the control options indicated that the assumptions made were reasonable and that the emissions were in line with those predicted. Background asbestos levels in the ambient air were found to be high and to exist both upwind and downwind of the plant for considerable distances (10 km). Emissions from small test plots were too low to be measured but the stability of the chemically stabilized and the soil-vegetated covers were excellent. Despite the high alkalinity of asbestos waste (pH 12), vegetation was grown on the soil to give a 95% cover, far in excess of the coverage required to prevent soil erosion.

This work was submitted in fulfillment of IITRI Project Number C6338, EPA Contract Number 68-02-1872, by the IIT Research Institute under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period March 20, 1975 to June 19, 1976 and work was completed as of June 30, 1976.

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables viii
Acknowledgment x

1. Introduction 1
2. Conclusions 4
3. Recommendations 6
4. Identification of Emission Control Options 8
5. Analysis of Emission Control 32
6. Field Test Program 40
7. Field Tests Results and Discussion 65
8. Appendices 112
9. References 153

FIGURES

Number		Page
1	Asbestos waste disposal without emission controls	11
2	Asbestos waste disposal process treatment options for fines	12
3	Asbestos waste disposal process treatment options for aggregates	13
4	Isopleths for one year of uncontrolled inactive pile emissions	29
5	Least cost combinations of emission control options	38
6	Chemically treated pile	42
7	Soil vegetation covered pile	43
8	Reject pipe at the dump	45
9	High volume sampler stations for area survey at Johns-Manville plant, Denison, Texas	46
10	Location of high volume sampler stations for survey in general area of Johns-Manville plant, Denison, Texas	47
11	High volume sampling stations at the plant dump, Johns-Manville, Denison, Texas	49
12	Field test piles site, Johns-Manville, Denison, Texas	52
13	Distribution of fibers > 1.5 μm upwind and downwind of the plant	67
14	Distribution of asbestos mass concentration upwind and downwind of the plant	68
15	Asbestos concentration distribution upwind and downwind of the plant as predicted by Climatological Dispersion Model	69
16	Fiber concentrations vs. time upwind and downwind from test piles	76
17	Comparison of fiber concentration and chrysotile mass concentration for emissions samples collected in vicinity of plant dump	83
18	Cumulative distribution of fibers by diameter	85
19	Cumulative distribution of fibers by length	86
20	Concentration of the chemical stabilizer in the surface of Pile 3 shown as a function of time	92
21	Comparison of daily rainfall and surface moisture on test piles over a six month period	96
22	Comparison of average surface moisutre on test piles at different intervals of time after precipitation	97
23	Comparison of vegetation coverage on Pile 2 and rainfall over six month period	105
24	Comparison of soil electrical conductivity with soil pH on Pile 2. Values measured for sandy loam are included for reference	107

FIGURES (Continued)

Number		Page
25	Typical comparison of channelling on a non-vegetated pile (control pile)	109
26	Typical comparison of channelling on vegetated pile	110
27	Collection of particles by free falling water drops	113
28	Load lugger modified with spraying system	114
29	Landfill operation	122

TABLES

Number		Page
1	Asbestos Cement Waste Emission Control Options	9
2	Some Size Enlargement Methods and Applications	15
3	Chemical Stabilizers	19
4	Emission Rates of Uncontrolled Inactive Pile at Several Ages	25
5	Asbestos Fiber Emission Concentration as a Function of Affected Area	27
6	Summary of the Control Options	30
7	Chemical-Vegetative Hydroseeding Costs	35
8	Emission Control Options - Least Cost Combinations	39
9	Emission Sources and Control Options	41
10	Desirable Stabilizer Properties	54
11	Effect of Chemical Treatments on Mechanical Properties of Asbestos Waste and Retention of Treatments after Simulated Rainfall	55
12	Waste Pile Tests and Measurements	57
13	Background Asbestos Concentration, Upwind and Downwind of the Johns-Manville Plant Dump, Denison, Texas; Results of OM Fiber Counts and AA Elemental Analysis	68
14	Plant Area Background Particle Counts Measured by Condensation Nuclei Counter	70
15	Optical Microscope Measurement of Fiber Emissions from Static Asbestos Cement Waste Test Piles, Sampled on Aug. 21, 1975	72
16	Optical Microscope Measurement of Fiber Emissions from Static Asbestos Cement Waste Test Piles, Sampled on Oct. 13, 1975	73
17	Optical Microscope Measurement of Fiber Emissions from Static Asbestos Cement Waste Test Piles, Sampled on Nov. 17, 1975	74
18	Optical Microscope Measurement of Fiber Emissions from Static Asbestos Cement Waste Test Piles, Sampled on Dec. 11, 1975	75
19	t Test of Average Upwind and Average Downwind Fiber Concentration Measurements	77
20	Control of Emissions from Fines Transfer Operations at the Dump; Measurements made with Royco Particle Counter	79
21	Comparison of Electron Microscope, Optical Microscope, and Atomic Absorption Data for Samples from Five Locations at the Johns-Manville Plant, Denison, Texas	80
22	Atomic Absorption Concentration Measurements and Optical Microscope Fiber Counts of Asbestos Emissions Collected on Millipore Type AA Membrane Filters; Air Samples Collected on Premises of Johns-Manville Plant, Denison, Texas	82

TABLES (Continued)

Number		Page
23	Analysis of Selected Individual Fibers for Crystallinity and Elemental Composition (Electron Microscopy; Samples Collected on Hi-Vol Membrane Filters at Asbestos Cement Waste Dump	84
24	Comparison of Fiber Aspect Ratios from Several Dump Emission Sources	87
25	Comparison of Magnesium Concentration and Magnesium to Calcium Ratio for Bulk Waste Fines (Whole), Waste Fines < 200 Mesh (75 μm), and for Samples Collected on Hi-Vol Filters at the Dump	89
26	Asbestos Emission Concentrations and Emission Rates for Dump Emission Sources	90
27	Wet Sieve Analysis of the Control Pile and Chemically Treated Pile	94
28	Penetration Resistance	95
29	Shelby Tube Bulk Density	99
30	Settling Plate Measurements	100
31	Soil Analysis of Test Samples	102
32	pH Measurements of Sandy Loam Soil Cover on Pile after Four Months	104

ACKNOWLEDGMENT

The cooperation of Johns-Manville in the performance of this contract is gratefully acknowledged. A sub-contract to Johns-Manville was negotiated through John Collins and John Mitchell of the corporate headquarters in Denver, Colorado. The plant manager at the Johns-Manville plant in Denison, Texas was Mr. L. I. Richards. A special thanks is offered to Mr. J. T. Armstrong, Environmental Engineer at the Denison plant, who executed his responsibilities on the program in an efficient and conscientious manner even while pressed to perform his normal plant functions.

Dr. W. A. Berg of Colorado State University acted as Consultant Agronomist to the program. His specialized knowledge was invaluable to the success of the program.

David E. Descratch of the EPA nurtured the program into existance, his enthusiasm and interest in the program was appreciated. Mary K. Stinson assumed the responsibilities of the EPA Project Officer at the mid-point of the program. She very quickly realized the importance of the study and has strived to maintain the program's objectivity.

A large number of IIT Research Institute staff have contributed to the program which was administered out of the Fine Particles Research Section; Manager, Mr. J. D. Stockham. The program was guided technically by Dr. Colin F. Harwood while Paul K. Ase served as Project Leader. The cost effectiveness analysis was very ably conducted by Jim Huff and Linda Huff. Field studies were conducted with the assistance of Erdmann Luebke, Paul K. Ase, Colin F. Harwood, and E. Aleshin. Soil studies were performed by E. Aleshin and D. Fedor. Electron and optical microscope determinations were made by George Yamato, Dr. Anant Samudra, David Jones and Usha Maru. Atomic absorption measurements were made by F. Lai.

SECTION I

INTRODUCTION

OBJECTIVE

Asbestos cement manufacturing waste piles are frequently located in high-density population areas. It has been recognized by the U. S. Environmental Protection Agency that the presence of asbestos waste dumps in these areas might constitute a health hazard to those people living in the vicinity of the dumps.[1]

The objectives of this program were two fold. The first was to define those procedures involved with the disposal of asbestos cement waste which were most significant as atmospheric emission sources and to consider methods of controlling their emissions. Then those methods found to be most cost effective were to be tested in a field demonstration program.

The asbestos industry is not a small industry. World consumption currently stands at about 5 million tons per year. Approximately 1 million tons are used annually in the United States. Asbestos cement products account for 70 percent of the total United States usage. Products made from asbestos cement include pipe, wall siding, roof shingles, wallboard, and insulation products. It is estimated that 5-10 percent of the product material is dumped as scrap, of which 10 percent is fine dust and 90 percent coarse scrap from trimmings and breakage and from products which have failed quality assurance testing.

The quantity of waste material from the asbestos cement industry is readily estimated. Of the 700,000 tons of asbestos used in asbestos cement products annually, 7.5 percent is scrapped. Since asbestos products usually contain only 25 percent asbestos, then the total quantity of asbestos cement products disposed of as scrap per annum is about 210,000 tons.

Over the years, the scrap products have grown into substantial waste piles. Dumping of the scrap is usually carried out with little effort to control the fugitive emissions associated with the various stages of the waste transfer and dumping operations. Frequently, they are located in industrial areas of high population and could constitute a health hazard to the local residents. The hazard associated with such piles is difficult to assess because the effects may not become apparent until some 20-40 years after the onset of the exposure.

ASBESTOS CEMENT PIPE PRODUCTION

The asbestos cement products industry is the largest user of asbestos accounting for 70 percent of all the asbestos used. The largest segment of the industry is the production of cement pipe. Fibrous asbestos in the cement gives it a high tensile strength and provides a less costly, easier to use alternative to other types of pipes which have been largely superceded by asbestos cement. Pipe is made in diameter range from 75 cm to 120 cm with lengths up to 4 meters.

Applications for the pipe are varied and include:

- Water transport -- potable, drainage and irrigation
- Sewage
- Industrial products
- Air/gaseous products -- heating, cooling, gas-venting

Asbestos cement is composed of Portland cement (40-55 percent), finely ground silica flour (24-33 percent), and well separated asbestos fibers (15-35 percent). Most asbestos cement products are made by a wet mechanical process although dry and extrusion methods are also practiced.

The wet process equipment is somewhat similar to that used in paper manufacturing. Asbestos is fluffed and separated in a willow and is then mixed with finely ground silica sand and Portland cement. Water is added to form a homogeneous slurry and the slurry is fed on a moving felt conveyor. The water is drawn through the felt by vacuum and a continuous asbestos cement sheet is formed. The sheet is wound onto a cylindrical mandrel until the pipe reaches the desired thickness. The pipe is then loosened electrolytically by producing gases between the mandrel and the newly formed pipe. After a short time, the mandrel is removed and the pipe cured in an autoclave.

After curing, the pipe is cut to size and the ends are trimmed in a lath. Finally, the pipe is tested to ensure that it can withstand given flexibility and pressure standards. Other sections of pipe are cut to form angular sections and machined to facilitate junctions. All of the pipe fragments and failed pipe sections are collected in containers and removed to the dump. Each cutting, sawing, and trimming station is swept by an air extraction system which conveys the dust to a central baghouse dust collector. Fine dust collected in the baghouse is removed periodically and taken to the dump to join the larger waste fragments.

SELECTION OF THE CONTROL TECHNIQUES

In order to provide a rational basis for the selection of the emission control techniques to field tested, a hypothetical model plant was invoked. The model plant was based on features of known existing plants with the exception that it was assumed that no emission control was currently practiced. Based on this model plant, a theoretical analysis was developed

using the standard environmental engineering cost-estimating procedures from which recommendations were made on the control technique to be used to obtain a given degree of emission control for a given level of cost.

Initially, a list of emission control options were assembled and examined as candidate techniques for the field studies. Then the degree of control to be anticipated from the application of each technique was estimated. This estimate was combined with an estimate of the cost to obtain cost effectiveness data. The individual control techniques were then combined in control strategies combining several techniques to cover each of the individual sources at the model plant.

Resulting from the analysis of the cost effectiveness of the various control techniques and control strategies, a least cost curve was developed. The curve was used to find the cost to obtain a certain level of emission control and the control strategies which must be used to achieve the selected level of control. Then the options to be field tested were selected from the least cost curve.

FIELD TESTING OF CONTROL OPTIONS

Field testing of the control options was performed at the Johns-Manville asbestos cement pipe plant in Benteon, Texas. The facility is located in a rural area with an excess of land upon which the waste pile is located. Waste pipe and baghouse waste fine material are dumped on a daily basis in an open dump. A bulldozer is used on a monthly basis to crush the pipe and smooth the fines over the pipe to form a level area. Thus, four main sources of emissions were identified: waste dumping; crushing and leveling; a new, active dump area; and an extensive, old, inactive area.

Four options were selected for field testing. Two options were concerned with the transfer of the fine baghouse waste to dump; they were bagging the waste in polyethylene bags and forming a slurry of the waste. Two options were selectnd for stabilizing the waste piles; for the active pile a temporary chemical stabilizer was selected, while for the inactive pile a permanent soil-vegetative cover was tested.

Field tests at the site were conducted to determine the asbestos emission background levels over a broad area surrounding the plant. Tests at the dump site were conducted to establish the emission levels from the dump and also the degree of emission control to be expected from the controls applied to the dumping activities. Emission testing was also attempted on small test piles using the chemical stabilizer and soil-vegetative covers. The stability of the test piles was assessed using soil mechanics test procedures.

SECTION 4

CONCLUSIONS

Asbestos cement waste disposal piles have been recognized as a significant source of asbestos emissions into the ambient air. Four dump mechanisms for asbestos emissions have been identified: (1) transfer operations as the materials are dumped, (2) crushing and leveling the waste to form piles, (3) active or new dump areas subject to vehicular traffic, and (4) inactive, long term, undisturbed waste piles.

A theoretical cost effectiveness analysis based on a hypothetical model plant was used to select control options for a field study. Based on this analysis, four emission control options were selected. Emissions from the transfer of baghouse fines could be reduced by bagging or slurrying the fines at the plant before dumping. Active pile emissions could be reduced by use of a chemical stabilizer. Inactive pile emissions could be reduced by application of a soil-vegetative cover. Application of bagging is estimated to reduce the emissions by 100% at an annual cost of $10,500, while slurrying the fine waste would reduce emissions by 85% at an annual cost of $4,100. The use of a chemical stabilizer on the active waste pile is estimated to reduce the emissions by 80% at an annual cost of $3,970; while a soil-vegetative cover is estimated to reduce emissions by 90% at an annual cost of $3,380. The costs estimated apply only to the defined model plant which is, however, regarded as typical for the industry.

Field tests conducted at the Johns-Manville asbestos cement pipe plant at Denison, Texas indicated that asbestos could be detected in the ambient air surrounding the plant for distances in excess of 10 km. The striking feature of the ambient air asbestos levels was the fact that they were found both upwind and downwind of the plant in equal concentrations. The reason for this effect is not known; it is theorized that the concentration levels result from re-entrainment.

It is believed that this finding is of considerable importance because of the possible adverse health effects which might be associated with the asbestos levels in the ambient air. Recent studies reported in the literature[1] have indicated an association between mesothelioma, an asbestos induced cancer, and the presence of an asbestos manufacturing plant with people dwelling nearby.

Emission testing of the waste fines dumping operation confirmed it to be a significant source of asbestos emissions. Application of the emission control practices of bagging and slurrying the fine waste substantiated the estimated reduction in the emissions. Crushing and leveling tests were

conducted and these activities were found to be significant emissions sources at the time of operation. It was calculated by atomic absorption analysis that asbestos was emitted at the level of 14,500 to 89,000 µg per second, depending on the meteorological conditions, from crushing activities; while levelling of the fines gave asbestos emissions of 48,000 µg per second for old fines and 300,000 µg per second for fresh fines.

Atomic absorption analysis was used to supplement optical and electron microscope data. Its use is restricted to locations where there is a known source of asbestos and where the background does not interfere with the sensitivity. Under suitable conditions, it can give more sensitivity than microscope data at a considerable saving in time and cost. It cannot give any direct information on the numbers of fibers observed.

Small scale test piles of asbestos waste material were constructed and stabilised against erosion by a chemical stabiliser and a soil-vegetative cover. Emission testing from the piles proved to be inconclusive. This was because the emissions from the test piles were extremely low as a result of the stabilising covers and their relatively small sizes (10 m diameter). In addition, the background asbestos levels, even in a position well removed from the main plant, were found to be clearly measurable. Soil mechanics engineering tests applied to the piles indicated that both the chemical stabiliser and the soil-vegetation effectively stabilised the test piles in terms of structural rigidity. A vegetative growth with a coverage well in excess of the 70% required as an effective surface stabiliser was established on the test pile in spite of the highly alkaline nature of the waste. While emission tests would have been desirable, it is concluded that a highly stable 30 cm layer of soil would effectively preclude the emission of asbestos from the covered waste.

SECTION 3

RECOMMENDATIONS

This study has shown that asbestos cement waste dumps are a significant source of ambient air asbestos. Clinical and epidemiological observations have clearly demonstrated the association between asbestos exposure and pulmonary fibrosis, carcinoma of the lung, and mesotheliomas; and other adverse health effects are suspected. While exact quantification between asbestos exposure levels and adverse health effects has not yet been established, it is recommended that emission control procedures be applied to asbestos waste disposal operations to mitigate this source of asbestos emissions.

Four primary waste dump sources of emissions have been identified. Baghouse waste fines can be bagged or slurried to virtually eliminate fugitive emissions. Crushing of pipe without the presence of asbestos fines would be a relatively minor emission source. Active sites in the absence of fine material would also form a low level source. Until fines are no longer dumped it is recommended that active sites containing pipe and fines waste be sprayed on a monthly basis with a chemical stabiliser. Long-term permanent covering of all inactive piles is recommended using a soil-vegetative cover. It is recommended that the depth of the soil cover should not be quoted unless specifications are also given for the soil and the local meteorological conditions.

Asbestos was found in the ambient air for a considerable distance surrounding the asbestos cement pipe plant. Because of the health hazards associated with asbestos it is recommended that further studies be initiated to:

1. Obtain more samples under different meteorological conditions to more precisely determine the source and the dispersion of asbestos from the source.

2. Develop an understanding of why the asbestos was found upwind of the plant as well as downwind in the ambient air.

3. Obtain predictive models giving population/exposure levels for plants located in high population density areas.

A large number of chemical stabilisation agents with great potential for emission control have become available in recent years. Information is needed on the comparative effectiveness of these new compounds, particularly with respect to their emission control capabilities. A search of the literature revealed only sparse information on their effectiveness for soil

stabilization and zero information on emission control. Since approximately 50 stabilizers are available, a laboratory screening study followed by wind-tunnel emission testing of selected material is indicated.

This study was directed at the asbestos cement waste disposal problem where emissions are of special concern because of their adverse health association. However, the approach to the problem using cost effectiveness estimations as a screening step, and the generalized conclusions reached, will be a value to many industries concerned with the problem of fugitive emissions.

SECTION 4

IDENTIFICATION OF EMISSION CONTROL OPTIONS

Three separate technological approaches may be utilized to mitigate the emissions from the waste materials of the asbestos cement products industry. The first two methods eliminate the problem at source by (a) reusing the material in the product stream and (b) altering the waste asbestos to an innocuous non-asbestos form. The third approach is to apply dust control and stabilization technologies to the waste material that has been dumped onto waste piles.

In spite of intensive efforts to reuse or to alter the form of asbestos cement waste, no economically viable process has yet been developed. Common practice in the industry at this time is to dump the material onto waste piles. Frequently the dumping is performed without the application of emission control technologies. In this section, the reuse and alteration of asbestos cement waste products is briefly reviewed. The asbestos dust emission control options which may be applied to waste dumping operations are then reviewed in detail. In Table 1, the control technologies which are reviewed in this section of the report have been listed.

WASTE REUSE

Waste reuse, when it is feasible, is the most satisfactory manner of dealing with the waste products. Unfortunately, only a limited quantity of the material may be recycled into the process stream. This is because the curing of asbestos cement products is a chemical recrystallization process which cannot easily be reversed. Thus, once the curing is effected the recycled material would have little more effect than an inert filler. The use of such a filler would lead to weaknesses in the product which, particularly in the case of asbestos cement pipe, must be capable of withstanding stringent quality control tests. Further, much of the waste is in the form of large broken fragments or aggregates. In order to use this material it would first have to be broken down or ground into fine powder form. This step is regarded as totally uneconomic.

Asbestos cement tile and other similar low strength forms of this product could form a ready market for the finely divided waste. The cost would be essentially that of crushing, bagging, and transporting less the cost for dumping.

The National Concrete Masonry Association estimates that 90% of the blocks produced by its members is to ASTM C-90 specifications. Tests have been conducted at Johns-Manville indicating the likelihood of asbestos

TABLE 1. ASBESTOS CEMENT WASTE EMISSION

CONTROL OPTIONS

A. Waste Reuse

1. Recycle to plant
2. Other economic products and uses

B. Waste Alteration

1. Chemical alteration
2. Thermal decomposition

C. Waste Dumping

1. Transfer operations control options
   a. enclosure for emission control
   b. fines -- suppression of emission
      slurry
      granulate
      bag
      wet
   c. aggregates -- suppression of emission
      crush
      bag
      wet
2. Waste dump control options
   a. active pile control -- during transport, dumping, crushing, and leveling
   b. inactive pile control
      chemical stabilization
      physical stabilization
      physical covering
      vegetative covering

cement waste containing blocks would meet the compressive strength requirements of this specification.

Steam-cured bricks have been made from asbestos tailings fines that met ASTM Specification C73-67 for grade SW and MW brick.[8] Manufacturing costs have been analysed and have been found to be competitive with the commercial products. Up to the present time, asbestos waste has not been used commercially to produce these bricks.

New ways to minimize the waste as well as new ways to feed back the waste into the manufacturing process to produce profit-making products is a matter of considerable concern and innovative effort by each manufacturer in the asbestos cement industry. At the present time, it is the expressed conclusion of representative members of this industry, in which various options for waste reuse have been attempted, that none of these reuse options are economic.

WASTE ALTERATION

Over 95% of the asbestos used in this country is chrysotile asbestos. Chrysotile has a cylindrical structure with magnesia on the outer surface and silica on the inner surface. An acid leach could be used to remove the magnesia and leave a cylindrical residue of silica. It would be useful to effect a prior separation of the asbestos from the cement waste to get efficient use of the acid.

Many hydrated magnesium silicates can act as cements if they are first decomposed by heating in air.[9] Thus, chrysotile asbestos waste may be converted to fosterite, a non-asbestos serpentine mineral, by heating to 700°-900°C. This might be used as a cement material for making steam cured asbestos cement products. Studies would be necessary to determine the conversion time factor to ensure that all of the asbestos was converted to fosterite. A further problem is that it would have to be established that fosterite was not itself a harmful material.

While both thermal and chemical decomposition are possible, they are not economically viable.

WASTE DUMPING

Waste is dumped only when no further utilization of the waste material is economic. Figure 1 shows a flow diagram of the accumulated waste and follows it to its final disposition in a present day operation. Fines are collected from baghouse filters and aggregates are accumulated from breakage, rejects, cuttings, and drillings. The wastes are recycled when the product specification permits. Otherwise, they are dumped and leveled, creating visible emissions at the same time, and eventually covered with earth.

The emission control options outlined in Table 1 have been placed into a process diagram for fines in Figure 2 and a corresponding diagram for aggregates in Figure 3. Efficient emission control requires a separation of

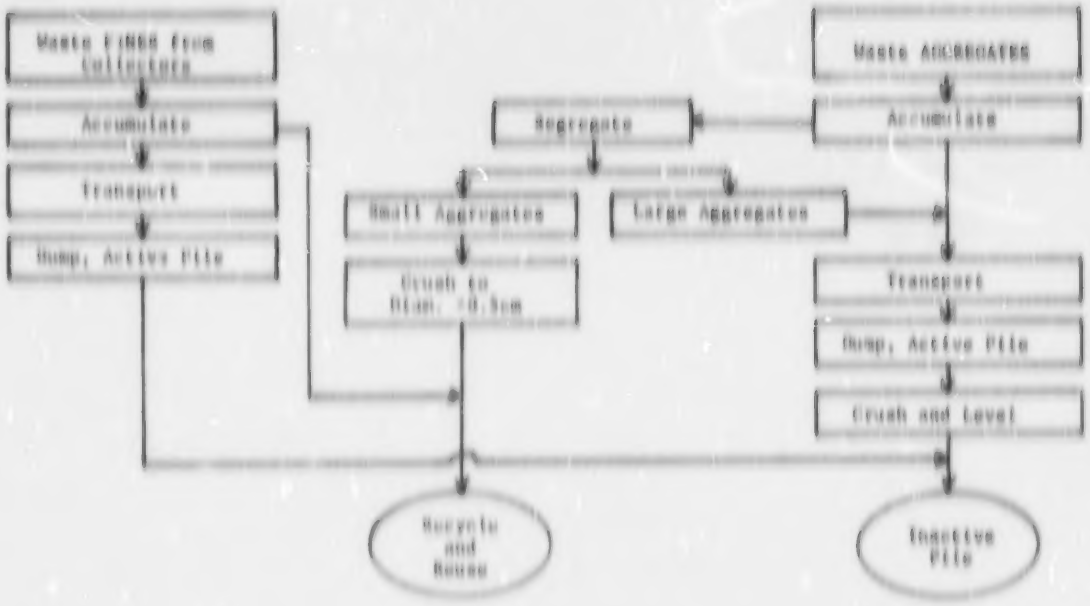


Figure 1. Asbestos waste disposal without emissions controls.

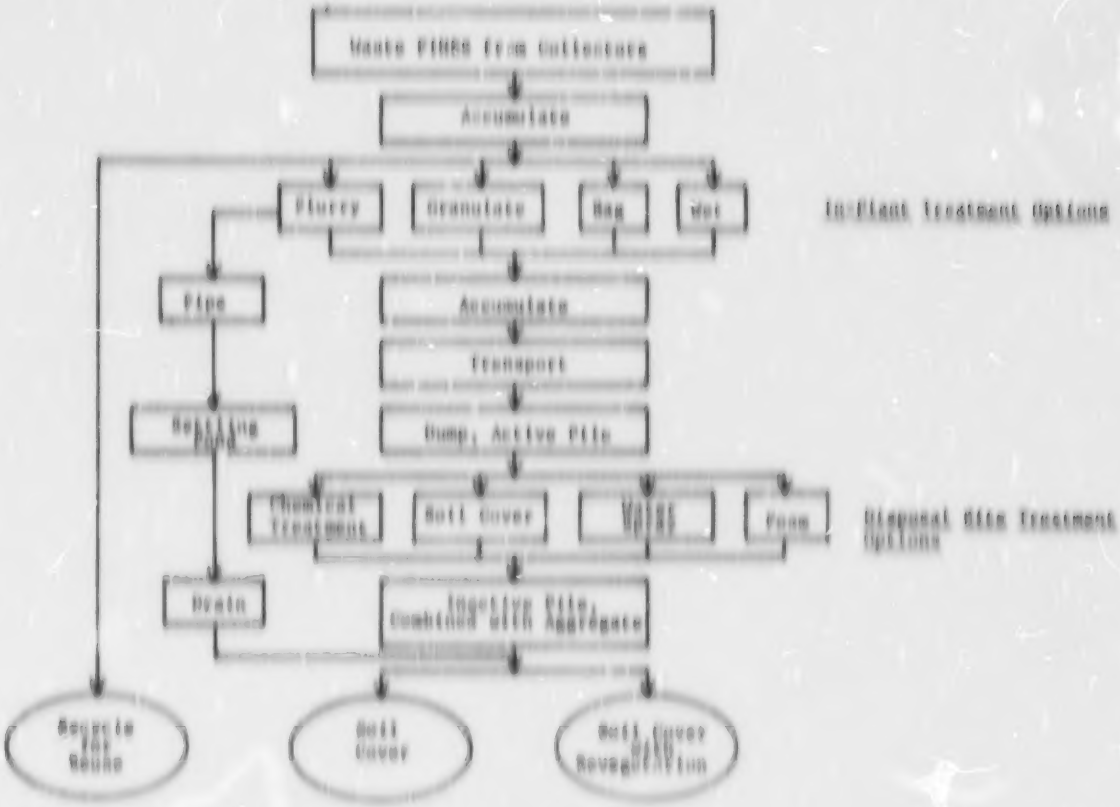


Figure 2. Asbestos waste disposal process treatment options for fines.

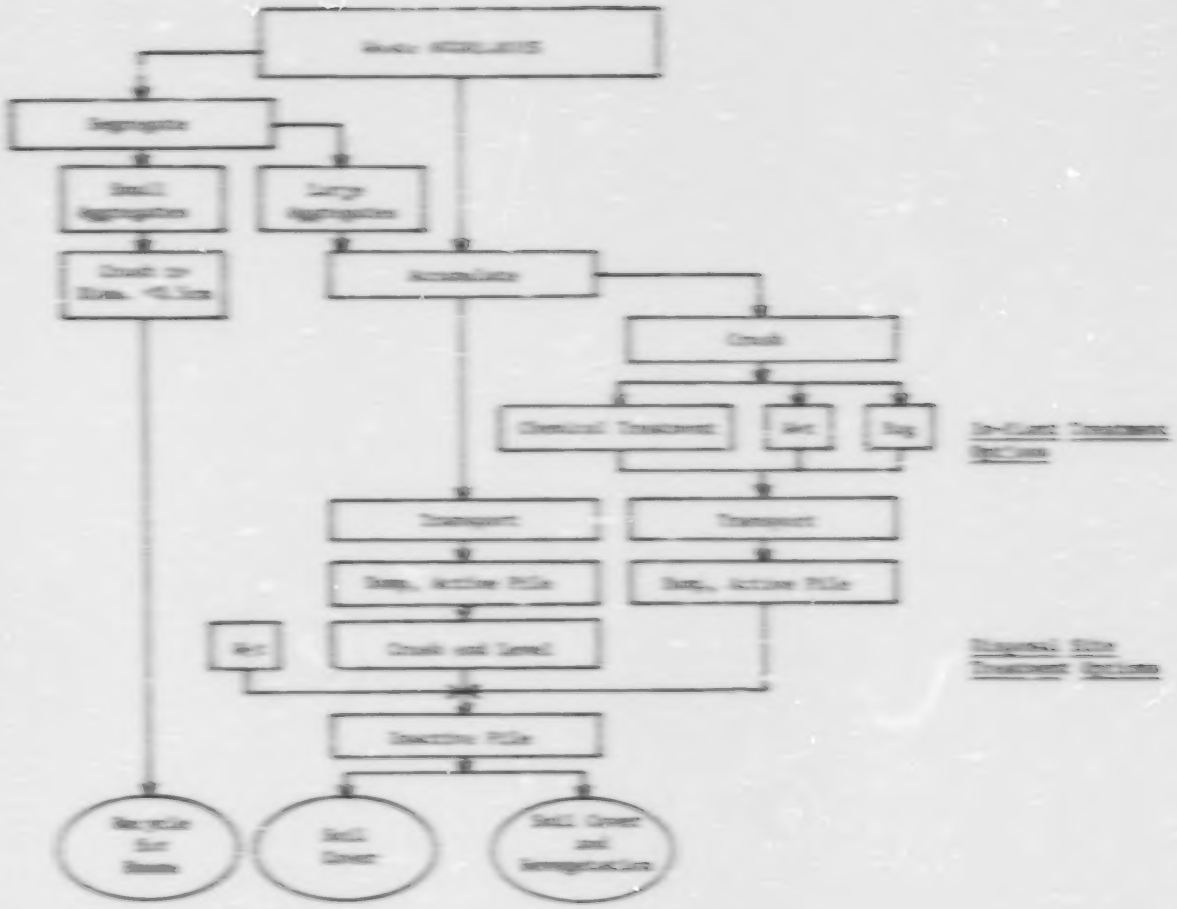


Figure 3. Alternative waste disposal process treatment options for aggregates.

fines from aggregates so that they can each undergo separate waste treatment optimized for control of their emissions.

Waste emissions have been identified with four basic sources. Besides the daily visible emissions created during dumping and during the subsequent once a month crushing and leveling operations, low level emissions continue to be released from exposed active and inactive dumps due to wind entrainment of loosened surface particles and erosion of aggregates by weathering.

In Plant Options

Short term and moderate term mitigations must be considered, as well as permanent disposal solutions. There is no single, all-purpose option to take care of all waste dump emission control problems, but a balanced use of a number of limited methods is required to achieve overall control of the waste asbestos emissions.

Control is difficult once emissions are created. Control should, therefore, begin in the plant as the waste is accumulated. Plant control processes which are being considered are:

- Crushing and sizing all waste
- Wetting bulk waste before particulate emissions are created
- Slurrying of fines and piping them to a settling basin
- Bagging waste in sealed containers which could be stored for reuse or dumped and covered without further treatment
- Granulation of fines
- Foaming of waste accumulations to prevent air entrainment and escape of particulates

By performing the crushing in the emission controlled environment of the plant, a great deal of the emissions released during the leveling operation can be eliminated. If the leveling itself is combined with the act of dumping, then emissions from that process can be very much reduced. Jaw crushers can accept large aggregates and are suitable for this purpose.

Once the coarse, large aggregates have been broken down, the fines can be separated out and treated. The fines can be wetted, granulated, or bagged and accumulated for dumping. The wetting could be performed with or without a stabilizer or a wetting agent.

A number of size enlargement methods are readily available for aggregation of the fines. Those which might be applied here are shown in Table 2. Pressure compaction in a roll press is an attractive method for aggregation. Large quantities of aggregates at low cost are claimed. The raw material is compacted as it is squeezed into the gap between two rolls rotating at different speeds.

TABLE 4. SOME SIZE ENLARGEMENT METHODS AND APPLICATIONS[5]

Method	Equipment	Applications
Pressure compaction	Roll type press	Clay type minerals, organic compounds, ores, charcoal, lime, phosphate rock
	Pellet Mill	Clays, carbon, fertilizers, animal feed
	Screw Extruder	Bauxite, plastics, clays
Agglomeration by tumbling	Inclined pan or disk, rotary drum agglomerator	Fertilizers, iron ore, mineral and clay products, finely divided solid waste products
Sintering and heat hardening	Traveling grate, rotary kiln	Ore, minerals, cement clinkers, solid waste products
Fluidized bed processes	Fluidized bed	Granulations for pharmaceutical tableting, liquid radioactive waste

The fines can also be formed into an aqueous slurry and piped to a settling basin. The basin could eventually be drained and covered for long term emission control. However, care should be taken to avoid causing a water pollution problem.

In the operational setup of options shown in Figures 2 and 3, the waste alteration processes are treated as an integral part of the waste treatment flow diagram.

Control of Active Piles

Those sections of a dump where material is still being dumped have been considered as "active sites". Correspondingly, "inactive sites" refer to those sections of the dump to which new wastes are not added and where vehicular traffic does not disturb the surface.

When an accumulation of waste is being dumped and leveled at an active site, a very high emission concentration is created when positive measures are not taken to control the emissions. The potential emission problems occurring during this activity depends on the effectiveness of the control measures being used in the in-plant waste control operations. If the waste consists only of smaller aggregates which have been well wetted in-plant, perhaps no control may be required except to prevent stirring up what is already on the dump. Foaming the surface of the dump might be effective in preventing this stirring up action. This could be more effective than spraying since a deep penetration of the wetting action would be required to offer the same degree of emission suppression as a thick layer of foam. A new foam successful in suppressing mine dusts is available for this option.[5]

During the time between the dumping and leveling operations, the emissions from the active pile are similar to those from the inactive pile. Chemical treatment of the surface of the dump with a stabilizing agent which decreases saltation particles could be effective for control of emissions from an active pile and from an inactive pile which is not yet covered.

Chemical Stabilization of Asbestos Waste

In order to apply state of the art chemical methods for asbestos waste stabilization, the possibilities of adapting soil stabilization techniques are attractive. A brief review of the technical information on this subject was made. Then commercial sources of material supplies were contacted and price information for these materials was obtained.

Quaternary ammonium salts of long-chain fatty acids have been known to improve the stability of soils for many years, as demonstrated in several studies at Iowa State University.[1,2,3] The mechanism of soil stabilization by these compounds is generally considered in terms of reduced water adsorption and improved orientation of water dipoles between soil particles. Dry soils form hard crusts and compact clusters because the residual moisture is present in oriented thin dipolar films that link the soil particles and hold them together. When the soil is wetted during a rainfall, the inter particle film layer increases considerably in thickness and dipole bridging

effects are greatly diminished. The resulting loss in soil strength can be alleviated by deposition of cationic organic compounds on the surface of soil particles, as these compounds will interact (electrostatically) with the negatively charged soil particles, imparting to them hydrophobic properties and thereby lessening their affinity for water. The reduced susceptibility of the soil for water adsorption is responsible for maintaining the strength of treated soil in aqueous environments. However, over treatment can render the soil so hydrophobic as to interfere with the capability of water dipoles to link the individual soil particles in a cohesive structure. It is apparent that the amount of treating compound must be controlled to ensure binding efficiency for the stabilizing agent.

The mechanism of soil stabilization by nonionic high molecular-weight compounds is different from that of ionic treating agents since the flocculation tendency of charged compounds is here replaced by the purely adhesive action of long-chain polymers. This action, reflected in the capability of some polymers to form inter-laminar complexes and vertical bridges at edge faces of silicate crystals is considered responsible for the effectiveness of polymers in soil stabilization.[10] A number of other high molecular-weight compounds that are capable of forming hydrogen bonds with exposed oxygen and hydroxyl groups have been found to improve the stability of soils by virtue of their adhesive properties.

Although a direct comparison between the stabilizing effectiveness of organic chemicals in the treatment of soil and asbestos waste is difficult, the silicate nature of serpentine (chrysotile) and amphibole (tremolite, actinolite) asbestos should present a number of anchoring sites for the attachment and adhesive bonding of polymer stabilizers. Soil and asbestos might not respond similarly to treatment with charged organic chemicals since chrysotile, unlike soil particles, carries a positive surface charge, as determined by its zeta potential (+30 mv). Possible benefits derived from the application of cationic soil stabilizers to asbestos waste would then result after stabilization by the entrapment of the asbestos fibers in the asbestos-occluding soil particles. Such entrapment, although not involving direct treatment, could prove effective in the control of asbestos emissions from waste dumps.

Candidate Materials

A survey of potential chemical treatments was made to find materials which have been used as stabilizers of soil and fibrous particulates similar to the present waste.

A number of polymers have been found effective in the stabilization of soil. These polymers include polyvinyl alcohol (PVA), polyacrylic acid (PAA), a copolymer of vinyl acetate and maleic acid (VAMA),[11] sodium alginate and polysaccharides,[12] unsaturated polyesters and epoxide resins,[13] and carbamideformaldehyde resins.[14] The stabilization of soils with PVA was found effective in surface applications at a 0.05% loading level[15] with no adverse effects on the emergence rate of wheat.[16] On the other hand, bituminous soil treatments, which are known to maintain their effectiveness for several years, have inhibited the growth of soil microbial populations

and reduced enzyme activity.[8] These relationships might be important in those instances where waste disposal areas would eventually be considered for rehabilitation and agricultural uses.

From a review of the published literature and conversations with representatives of industry, information was obtained on the applicability of several chemicals and proprietary treating agents for the stabilization of asbestos waste. These chemicals included charge-carrying organic compounds, polymeric binders, and trademarked products of not well-defined composition. A list of these chemicals with price quotation on a unit mass basis as available is presented in Table 3.

Control of Inactive Piles

The chemical treatments which could be used to stabilize active piles could also be used to stabilize inactive ones. However, the chemical treatments can only offer short to moderate term stabilization. Long term emission control can be obtained only by either chemical alteration of the asbestos waste itself or by a permanent cover on the waste dump.

A bare soil cover, alone, is not always stable and, given unfavorable conditions, could blow away. A soil cover with a stable vegetative growth is more esthetically pleasing and would offer the surest, most lasting emission control over an inactive dump.

Agronomists have been studying the revegetation of mine waste dumps and the over burden from surface coal mines.[9,10] Dr. W. A. Berg,[11] consultant agronomist to this program, has studied the vegetative stabilization of wastes from a number of different metal ore mill tailings and spoils from open pit and strip mines.

The use of stabilizers of a resinous adhesive type has been reported by Dean and Haven of the Bureau of Mines.[12] These stabilizers have found success in helping promote revegetative growth directly on fine mine tailings. The stabilizer is water soluble and could be useful for stabilizing the vegetative soil cover during germination and early growth.

The methods used to get vegetative cover was similar for all these workers. Although in some cases planting directly on the waste was successful, generally a layer of earth was laid down on the dump. Then a water slurry of seeds, fertilizer, and mulch was sprayed on the surface, giving a rapid uniform distribution of all the necessary materials at one time.

In asbestos cement waste, the cement is quite basic and requires a soil cover to get healthy plant growth. On the other hand, soils generally lack anion exchange capacity. Plants require a number of minerals from the soil which occur as anions. These include phosphates, nitrates, sulfates, borates, and molybdates. The asbestos could provide the stable anion adsorption sites lacking in the clay of the soil which could be used after sufficient neutrality has penetrated the waste.

TABLE 3. CHEMICAL STABILIZERS

Product	Chemical Identification	Supplier	Cost, Dollars/kg
Amine D Acetate, 50%	Stabilized abietyl amine	Hercules, Inc., Hattiesburg, Miss.	1.38
Polyrad 1110A	High molecular-weight amine ethylene oxide adducts	Hercules, Inc., Hattiesburg, Miss.	1.72
Vinyl Emulsion	Water emulsion of aliphatic resin	Hercules, Inc., Kalamazoo, Mich.	0.28
Defloc 50	Cationic polymer	Hercules, Inc., Milwaukee, Wisc.	0.37
Abitol	Hydroabietyl alcohol	Hercules, Inc., Burlington, N.J.	1.85
Paracol emulsion	Wax-rosin emulsion	Hercules, Inc.	—
Piccolyte Dipentene	Poly...pene adhesive resin	Hercules, Inc.	—
Reten 421	Anionic acrylic polymer	Hercules, Inc., Hopewell, Va.	3.09
Neuphor 100	Anionic emulsion	Hercules, Inc., Milwaukee, Wisc.	0.51
Kymene 557	Cationic polyamide-epichlor-hydrin resin	Hercules, Inc.	—
Lendloch XA1440	Adhesive binder	3M Co., St. Paul, Minn.	—

TABLE 3. (Continued)

Product	Chemical Identification	Supplier	Cost, Dollars/kg
Laten M345 or M366	Laten binder	Dowell Div., Dow Chemical Co., Tulsa, Okla.	0.53/[illegible]
Elvanol	Polyvinyl alcohol	E.I. Du Pont de Nemours & Co.	—
Vinylac	Polyvinyl acetate, tackified dispersion	Borden Chemical Co.	1.22
ARQUAD 2MT	Quaternary ammonium compound	Armak Chemicals Co.	—
ARQUAD 2S	Quaternary ammonium compound	Armak Chemicals Co.	2.40
Ethomeen T/12	Tertiary aliphatic amine	Armak Chemicals Co.	1.60
Crude Amine	Amine compound, unpurified	Armak Chemicals Co.	0.75
Krilium CRD-106	Vinyl acetate/maleic acid	Monsanto Chemical Co., St. Louis, Mo.	—
Sodium alginate	Sodium alginate	Kolsken Co., Teaneck, N.J.	4.41
Polyacrylic acid	Polyacrylic acid amine	Rohm & Haas Co., Philadelphia, Pa.	—
Superfloc 16	Flocculant	American Cyanamid Co., St. Louis, Mo.	—

TABLE 3. (Continued)

Product	Chemical Identification	Supplier	Cost, Dollars/kg
Coherex	Resinous binder	Witco Chemical Co., Hammond, Ind.	0.095/1
Rezosol 5411B	Cationic resin emulsion	E.F. Houghton Co., Philadelphia, Pa.	0.065/1
Dextran	Dextran	Howard Hall Co., Cos Cob, Conn.	8.82

SECTION 5

ANALYSIS OF EMISSION CONTROL

EMISSION CONTROL COST EFFECTIVENESS ESTIMATES

In Section 4 of this report, the control techniques which might be applied to the task of reducing the emissions from asbestos cement waste dumping operations are discussed. In this section, the cost effectiveness of these techniques are estimated from the estimate of the cost of application of each technique and from the estimated reduction in the emissions brought about by that technique.

In order to estimate the cost and emission reduction factors, a hypothetical typical plant has been developed as a model. The plant is based on the Johns-Manville plant at Denison, Texas, as discussed in Section 3.

The estimation of fugitive emissions from a site is a difficult procedure and yet such estimates must be developed in order to provide a logical basis for the application of controls in the field testing program. The emission rates estimated in this study were found to be quite reasonable and realistic when compared to those obtained subsequently in the field study. They have been left unchanged in this section in order to present the methodology of control technology selection based on environmental engineering judgement and estimation techniques.

MODEL PLANT DETAILS

A model plant which manufactures asbestos-cement pipe is considered to be located in an urban area in the southwestern part of the United States. No effort is currently being used to mitigate the emissions from the waste dumping operations.

There are two types of asbestos-containing waste material originating in the plant which are taken to the dump:

- Reject asbestos pipe and scrap -- 13.2 metric tons per day
- Fines from the baghouse -- 0.9 metric tons per day

The daily production of asbestos cement pipe is about 200 metric tons. Production continues for six days per week for 50 weeks per year. The composition of the waste is approximately:

Cured Portland Cement -- 45%

Quartz silica -- 30%

Asbestos -- 25%

It is assumed to have a density of 1,760 kg/m^3 (100 pounds/ft^3).

The emissions from the dump area are assumed to have the same composition as the dumped waste (25% by weight of asbestos). It is further assumed that every nanogram of asbestos releases into the atmosphere 1,000 asbestos fibers as determined by electron microscopy.

Emissions from the dump area are considered to arise from four basic sources:

- Daily dumping of the waste onto the active dump area
- Crushing and leveling of the reject pipe by a bulldozer once a month
- Weathering of the active pile
- Weathering of the inactive pile

The active part of the dump is where waste material is currently being dumped. It is subject to disturbance by vehicular traffic and bulldozer activity, it has an assumed area of 810 m^2 (0.2 acres). At the end of one year, it is 3 meters deep and a new active dump area will be started. The southwestern area location means that the area will be dry (less than 1 m of rain annually) and, thus, the emissions will be in a high category.

ESTIMATION OF EMISSION FACTORS

Emissions from the Active Dump Site

Based upon the 14.1 metric tons/day of waste material generated, 2,400 m^3/year must be disposed. The active dump site at this plant is 810 m^2. At the end of one year, the pile will be 3 m deep, at which time a new dump area will be started.

This plant is located in that part of the southwest which receives less than 1 meter of rain annually. Thus, the surface of the waste pile is extremely dry most of the year and favors relatively high emission rates. In a study by PEDCo,[8,9] particulate emissions from tailings piles were developed for various climatic conditions. Because of the high moisture evaporation rate and the large number of fine particles contained in the asbestos pile, the highest listed emission rate was used for this waste material, 3,583 metric tons/km^2/yr, of which 25%, or 0.7 metric tons/yr, would be asbestos. Thus, the average emission rate from the active pile would be:

0.09 kg per hour

or 90×10^{9} nanograms per hour

or 90×10^{12} nanograms per hour*

Emissions from the Crushing of Rejected Pipe

The waste consisting of rejected pipes and scraps amounts of 13.2 metric tons/day at this plant. Visible emissions can be observed during the crushing operation at the dump, indicating that this operation may be a significant source of emissions. It was assumed that 0.01% of the rejected material becomes airborne, of 32.5 kg/month (1.3 kg/day of operation). The pipe is crushed for one day a month. The emission rate is averaged over the entire year with 25% by weight of this emitted material considered to be asbestos, yielding the following:

0.009 kg per hour

or 9×10^{9} nanograms per hour

or 9×10^{12} asbestos fibers per hour*

Emissions from the Inactive Pile

The emissions from the inactive pile are a function of the size of the pile and the rate of emissions coming off the pile. It has been assumed that the emission rate from an asbestos pile asymptotically approaches 1/5 the emission rate of the active pile, thus, the emission rate is assumed to rapidly approach 22.2 kg/hr/km^2 and remains constant at 22.2 kg/hr/km^2 once an asbestos pile becomes inactive.

The older the asbestos facility is, the larger the inactive pile becomes and the greater the emissions from this source. In the model plant, the inactive pile contains five years of waste material. However, in another five years, the emissions from the inactive pile will double. Thus, the inactive pile must be prevented from becoming the primary emission source.

If the emissions from the inactive pile are uncontrolled, the annual emission rate increase, proportional to the increase in pile area, will be:

0.018 kg per hour

or 18×10^{9} nanograms per hour

or 18×10^{12} asbestos fibers per hour*

---

* A conversion factor of 1,000 fibers per 1 ng was used; this is in agreement with the literature and also with the results obtained from electron microscope data obtained during this study, see page 50.

Total Emissions from Asbestos Disposal Operation

The total emissions from the dump is the sum of the emissions from the four primary sources. The total emissions for an uncontrolled dump at several ages is shown in Table 4. The emissions from the inactive pile can be seen to depend upon the number of years of accumulated waste. A three fold increase in emissions occurs as the waste accumulates over a period of twenty years. Thus, although the annual increment in the emission rate from the inactive pile might be considered negligible, the long term effects are cumulative and can become the dominant source of emissions.

TABLE 4. EMISSION RATES OF UNCONTROLLED INACTIVE PILE AT SEVERAL AGES

	Emission Rates, kg/hr		
Emission Sources	1 yr	10 yrs	20 yrs
Active Dump Site	0.090	0.090	0.090
Crushing of Reject Pipe	0.009	0.009	0.009
Dumping of Fines	0.034	0.034	0.034
Inactive Pile	0.018	0.180	0.360
TOTAL EMISSION RATE	0.151	0.313	0.493

Annual Average Ground Level Airborne Asbestos Concentration

If one assumes the asbestos that becomes airborne will remain suspended, then the dispersion techniques utilized for gaseous pollutants can be applied to asbestos. Using Turner's Workbook for Atmospheric Dispersion Estimate,[7] the area affected by various asbestos fiber concentrations was calculated. The annual average concentrations were based on the following assumptions:

- All asbestos emissions originated from a single ground level point source, with an average wind speed of 2 m/sec.
- An average stability class of "D", as described by Turner, was assumed.
- A prevailing wind direction is assumed. For the purposes of this study, we will assume that the people downwind of the plant will be the only ones affected by the asbestos emissions.

Tables 5A, B, and C were developed from isopleth diagrams for ground level sources.[8] The isopleths diagram for one year of uncontrolled pile emissions is shown in Figure 4.

Best available data were used to estimate emission concentrations for the hypothetical plant. The estimates of emission concentrations at the dump are about twice as great as the concentrations estimates from measurements obtained in subsequent field tests.

ESTIMATED COST OF EMISSION CONTROL OPTIONS

The sources of asbestos emissions were identified earlier in this section as: inactive pile, active pile, fines dumping, and crushing of the reject pipe. In the model plant, no dump emission control efforts are currently being made. Each year, the size of the inactive pile increases, as do the emissions from this source. Because of the effect of long-term emissions from the inactive pile, the emission control options are limited to the single method that eliminates this source permanently at the least cost. Thus, in order to properly evaluate the overall costs, it will be assumed that only one year's accumulation of inactive waste material is included when estimating the annual control costs.

The following rate estimates were taken from the model asbestos plant (see Table 4):

Emission Source	Emission Rate, kg/hr
Active pile	0.090
Crushing of reject pipe	0.009
Fines dumping	0.034
Inactive pile	0.018
TOTAL	0.151

The capital and operating cost for various control schemes were estimated as well as the degree of emission control achieved. Capital investments were amortized over their estimated life assuming a 10% interest rate. The following sections describe each control method evaluated, and a more detailed description is presented in the Appendix. Table 6 summarizes the results of these cost estimates.

Emission Control During the Fines Dumping Operation

In the model asbestos plant, three baghouses are used to collect the fines. The storage bins in which fines are collected are emptied once per day, and each one typically contains 0.3 metric tons of material with a bulk specific density of 0.4 gm per cm^3. The fines are currently transported daily to the active pile by a 2.4 cu meter "load-lugger", which makes two

TABLE 5. ASBESTOS FIBER EMISSION CONCENTRATION AS A FUNCTION OF AFFECTED AREA

A. One Year of Uncontrolled Inactive File Emissions

Emissions Affected Area (km^2)	Asbestos Fiber Emission Concentration in Affected Area	
	No. of Fibers/m^3	Nanograms/m^3
0.0010	1.3×10^8	1.3×10^5
0.010	1.3×10^7	1.3×10^4
0.035	4.0×10^6	4.0×10^3
0.07	2.0×10^6	2.0×10^3
0.10	1.3×10^6	1.3×10^3
1.0	1.5×10^5	1.5×10^2
6.0	0.3×10^5	0.3×10^2
10.0	0.2×10^5	0.2×10^2

Waste Pile Emission Rate of 0.151 kg/hr = 151×10^9 nanograms/hr
= 0.419×10^8 nanograms/sec.

TABLE 5. (Continued)

B. 10 Years of Uncontrolled Inactive Pile Emissions

Emissions Affected Area (km^2)	Asbestos Fiber Emission Concentration in Affected Area	
	No. of Fibers/m^3	Nanograms/m^3
0.0010	2.7×10^8	2.7×10^5
0.010	2.7×10^7	2.7×10^4
0.10	2.7×10^6	2.7×10^3
1.0	3.1×10^5	3.1×10^2
10.0	0.4×10^5	0.4×10^2

Emission Rate of 0.213 kg/hr.

C. 20 Years of Uncontrolled Inactive Pile Emissions

Emissions Affected Area (km^2)	Asbestos Fiber Emission Concentration in Affected Area	
	No. of Fibers/m^3	Nanograms/m^3
0.001	4.2×10^8	4.2×10^5
0.010	4.2×10^7	4.2×10^4
0.10	4.2×10^6	4.2×10^3
1.0	4.9×10^5	4.9×10^2
10.0	0.7×10^5	0.7×10^2

Emission Rate of 0.493 kg/hr.

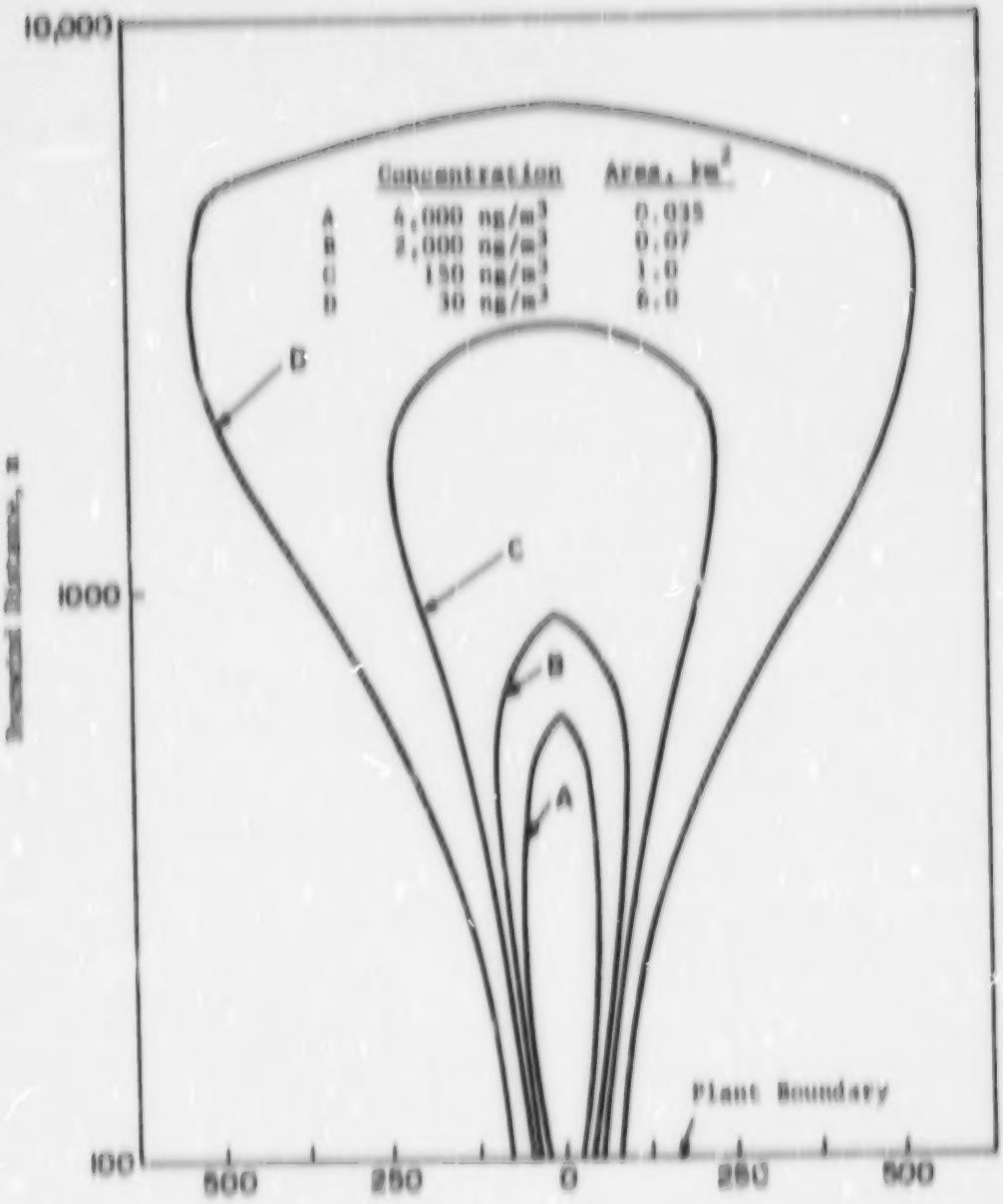


Figure 4. Isopleths for one year of uncontrolled fugitive pile emissions.

TABLE 6. SUMMARY OF THE CONTROL OPTIONS

Control Method	Total Annual Cost, $	% Reduction in Emissions From: Fines Dumping	Aggregate Crushing	Active Pile	Inactive Pile	Total Emissions
1. Water Spray at Fines Dumping	2,800	10	—	—	—	2
2. Water & Surfactant at Fines Dumping	3,400	20	—	—	—	4
3. Agglomeration of Fines with Water	10,000	90	—	5	—	23
4. Agglomeration of Fines with Binder	13,000	96	—	25	—	35
5. Water Slurrying of Fines	4,100	85	—	—	—	19
6a. Chemical Binder with Water + 0.75% Binder	5,600	85	—	45	—	46
6b. Chemical Binder with Water + 0.10% Binder	5,400	85	—	27	—	35
6c. Chemical Binder with Water + 0.10% Binder	5,000	85	—	14	—	27
7. Bagging of Baghouse Fines	10,500	100	—	45	22	52
8. Soil-Vegetative Control of Inactive Pile	3,380	—	—	—	90	11
9. Water Spray on Active Pile	3,570	—	—	50	—	30
10a. Chemical Stabilize Active Pile once/week	8,970	—	—	90	—	54
10b. Chemical Stabilize Active Pile once/month	3,970	—	—	80	—	48
11. Land Filling Active Pile once/month	8,700	—	—	73	20	46

trips per day. Any costs associated with the various control schemes are only the costs incurred above the current practice.

Fines Dumping Control by Water Spray at Dump Site

The load-lugger was modified with a water spray system that can be operated when dumping the fines. The efficiency of water droplets for removing fine particles from the air is very low, and typically only 10% removal can be expected for the micron size particles.

The capital investmate is estimated at $3,700, with an expected life of five years. The annual cost (operating + capital) for this system is estimated at $2,800/year.

Fines Dumping Control by Water + Surfactant Spray at the Dump Site

Through the addition of a surfactant or wetting agent, the surface tension of water can be lowered by a factor of 2 to 3. Thus, the ability of water to cover the surfaces and to agglomerate particles will be increased. It was assumed the surfactant doubled the collection efficiency of the water to an overall level of 20%.

The installed cost for this system if $4,000, with an annual cost of $3,400/year.

Fines Dumping Control -- Agglomeration with Water

Pelletising machines have been successfully used for agglomerating asbestos dust fines, utilising 15-40% moisture. For this option, one pelletising disc machine was installed along with all the necessary auxiliary equipment. Transport of the fines to the pelletising disc was accomplished by use of the load-lugger.

It is estimated that by pelletising the asbestos fines, there would be a 90% reduction in the emission from the dumping operation. In addition, a 5% reduction in the emissions from the active pile would be achieved if the fines are pelletised.

The capital investment for the disc pelletiser plus all auxiliary equipment is $25,000, with an estimated life of 10 years. The annual cost for the alternative is $10,000/year.

Fines Dumping Control -- Agglomeration with a Chemical Binder

Up to a ten fold increase in crushing strength of pellets can be obtained through the use of a chemical binding agent with the pelletiser. It was estimated that this binder would reduce the emissions from the active pile by 25%, while the fines dumping operation would be reduced by 90%, the same as agglomerating with water. The chemical binder adds $1,000/year to the cost of the pelletising operation, or a total cost of $11,000/year.

Fines Dumping Control -- Water Slurry

By slurrying the fines prior to dumping, a significant reduction in emissions can be realized. The present load-lugger is not suitable for slurrying because it has no facilities for mixing the fines and water. It was assumed that a used cement mixing truck is purchased for $10,000 and has a useful life of five years. A reduction in emissions of 85% from the dumping operation was assessed. The annual cost for this control method is calculated at $4,100/year.

Fines Dumping Control -- Chemical Binder with Water Slurry

By using the same cement mixer truck described in the previous section and adding a binding type chemical such as polyvinyl alcohol to the water slurry, an even greater reduction in emissions can be achieved. Control of the dumping emissions would be the same as that achieved with the water slurry, 85%; however, there would be an increase in control efficiency for the active pile emissions. The increased control efficiency of the active pile emissions is a function of the chemical concentration. The following reductions were estimated:

Wt. % Binder Added to Fines	Active Pile Emission Reduction
0.33	45
0.20	27
0.10	14

The capital cost is the same, $10,000, for the cement mixer truck, and the annual cost varies with the chemical dosage:

Wt. % Binder Added to Fines	Annual Cost ($)
0.33	5,800
0.20	5,400
0.10	5,000

Fines Dumping Control -- Bagging of Baghouse Fines

The bagging of the fines should be an extremely effective method of controlling both emissions from the fines dumping operation and the active pile. Polyethylene bags, 3 mils thick, with a capacity of 15 kg were utilized in a manual operation which employed a used pick-up truck fitted with a bag holder.

The emissions from the dumping operation were assumed to be completely controlled if this technique were used. Half of the active pile emissions originate from the baghouse fines and the other half from the rejected crushed pipe and scraps. Utilizing a 10% breakage rate of the bags through the year, the emissions from the total active pile should be reduced by 45%.

An initial capital investment of $5,000 is assessed with a useful life of five years, and the annual cost is estimated to be $10,500/year.

Control of the Active Pile Asbestos Emissions

The active pile consists of fines from the baghouses (0.9 metric tons/day) and crushed reject pipe and scraps (13.2 metric tons/day). The reject pipe is crushed monthly and then placed in the active pile. Because of space limitations, the reject pipe must be crushed to reduce the volume of waste material.

Active Pile Emission Control by Water Spray

By keeping the active pile damp throughout the year, a 50% reduction in emissions is possible. In order to keep the active pile damp, a 1,000 gallon tank truck was purchased and equipped with a spray system. The capital investment is estimated at $10,000 with a useful life of 10 years. The annual cost is estimated at $3,570/year.

Active Pile Emission Control by Chemical Stabilization

Chemical stabilization is an effective method of controlling emissions. The expected life of a binding agent is a function of the prevailing weather conditions, and little data is available in this area. Using 100 gm/m^2 of polyvinyl alcohol, two different application frequencies were assumed. Applying once per month, the emissions from the active pile were assumed to be reduced by 80%. By increasing the application frequency to once per week, a 90% reduction in emissions was considered possible. The capital investment in both cases is $10,000 for a 1,000 gallon tank truck equipped with a spray system. The annual cost varies with the application frequency:

Application Frequency	Annual Cost ($/yr)
1/month	$3,970
1/week	$8,970

Active Pile Emission Control Using Foaming Agents

Foaming agents have been successfully used to reduce the airborne dust levels in mining operations.[illegible] The use of foams for preventing particles from becoming airborne from dumps has not been evaluated.

There appears to be no advantage of foaming the active pile compared to the use of a chemical binder. In order to offer any advantage, the foam must be long lasting (greater than a week), which is [illegible] the case. Once the foam collapses, this method offers no advantage. Because more equipment is needed and chemical costs are higher with a foaming unit compared to a chemical binder, it is a more expensive approach without any increase in efficiency.

Active Pile Emission Control by Landfilling

If the entire active pile is buried once a month right after the reject pipe is crushed, an effective control method would be realized. A 15 cm thick dirt cover will be used to cover each month's accumulation. Assuming No erosion through the year, plus the one month of waste material exposed at any given time, the overall efficiency of this approach was estimated at about 70%. In addition, there would be a reduction in the emissions from the inactive pile of perhaps 20%.

A bulldozer would be required for this operation, and its approximate cost is $18,000. If a life of eight years is assumed, the annual cost is estimated to be $2,700/year.

Control of the Inactive Pile Asbestos Emissions by Vegetative Cover

Each year, 2,400 m^3 of waste material is accumulated in the waste pile. At the end of each year, a new active dump site is started and the existing pile becomes inactive.

The total surface area of this pile is approximately 1,400 m^2. If the top of the pile is covered with 15 cm of dirt and the sloping sides with 30 cm of dirt, approximately 350 m^3 of dirt would be required.

The control method selected for the inactive pile must provide a permanent cover. A combination vegetative-chemical stabilization approach was assumed to be the method most likely to yield a permanent cover.

The pile is structurally unstable; thus, a small bulldozer is used to spread the dirt. A hydroseeder applies the seeds, chemical stabilizer, fertilizer, and water, and then hay is spread over the pile to protect the seeds from washing out.

Because the model plant is considered to be located within a city, excess land is at a minimum, and the dirt cover will be purchased from a local source. The following cost estimate in Table 7 was prepared, updating all referenced cost information to January 1975, dollars.

TABLE 7. CHEMICAL-VEGETATIVE HYDROSEEDING COSTS

(January 1975)

Item	Unit Cost	Annual Cost ($)	Cost per Acre ($)
Delivered Dirt	$6/m^3	2,100	6,000
Spreading of Dirt	$30/hr for bulldozer rental	270	840
Seed	$0.50/lb	20	60
Fertilizer	$0.20/lb	10	30
Hydroseeder	$15/hr	60	100
Soil Seal	$0.02/gal	20	50
Water Truck	$25/hr	100	150
Labor, including watering, maintenance, etc.	$8/hr	800	1,500
TOTAL COST		3,380	8,700

The cost of treating one acre of asbestos waste material with the system listed above is significantly higher than "typical" reclamation costs reported in the literature for various types of tailing piles. There are three major reasons for this apparent discrepancy:

1. A cost of $6/m^3 of delivered dirt was assumed in this study. The cost estimated in the literature assume the dirt is available at no cost on site.

2. A labor charge of $8/hr was utilized for this asbestos plant, as compared to $3-4/hr utilized in the literature.

3. Reclamation of one acre or less of waste asbestos is much smaller than most reclamation projects. Large savings (per acre) are realized when reclaiming larger tailing piles, due to economies of scale.

PEDCo[8] estimated that a combined chemical-vegetative stabilization control method would reduce particulate emissions by 90%. Once the vegetation becomes well established, we believe this control method will be 100% efficient. Thus, we assumed that each inactive pile treated with the combined chemical-vegetative method will emit 10% of the uncontrolled emissions in the first year, and no asbestos emissions after the first year.

Control of the Emissions from the Inactive Pile

Each year the waste material from the model asbestos plant is disposed of on the plant's property, and the size of this inactive pile grows ever larger. Accordingly, the asbestos emissions from this pile also continue to increase. Because the waste material has a high level of alkalinity, little or no vegetation grows on this pile, and the emissions are not naturally reduced. Obviously, the probability of effects on the surrounding community increases each year with the growth in asbestos emissions from the inactive pile.

The emission rate from the inactive pile after 20 years of accumulation has been estimated to be 0.493 kg/hr. Thus, the inactive pile is a major asbestos emission source and must be controlled on the assumption that a health threat is posed by its uncontrolled presence. Table 4 gives the relative estimated magnitudes of the various emission sources; it can be seen from this table that inactive waste piles become the major contributor with time and as such must be controlled. The cost effectiveness analysis of the control options evaluated all include the elimination of emissions from the inactive pile source.

SELECTION OF CONTROL METHODS FOR FIELD TESTING

In Table 5, the control options, their estimated costs, and the effectiveness in reducing the emissions from each of the four primary sources discussed in the section have been listed. Based on the estimated cost and efficiencies for various control options, a control scheme can be selected for field testing. The control options have been grouped together into

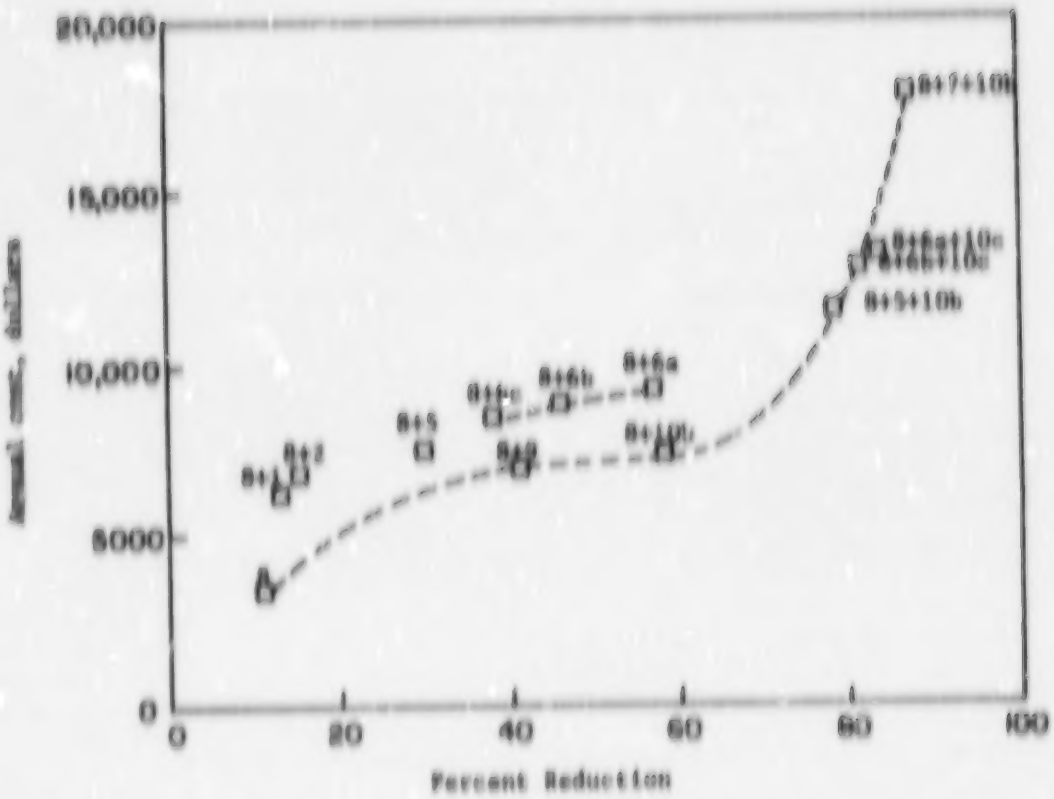
combinations which result in a reduction in overall emissions of 11% to 87% and range in cost from $3,380 to $18,130 per annum for the hypothetical plant considered.

The relative merits for the various schemes can be more readily seen from the graph drawn in Figure 5 which plots the least cost control curve for the combinations of control options listed in Table 8. The most critical region occurs in the 60% to 80% part of the curve. Increasing the control efficiencies beyond this point led to rapidly increasing cost, primarily because three of the four sources must be controlled to achieve an increased level of control.

Analysis of the costs quite clearly shows that control of the active and inactive piles is the most cost effective control which may be applied. A soil-vegetative cover is recommended for the long-term control of inactive waste piles while the active pile should be stabilized using a chemical stabilizer. It is estimated that with these two sources properly controlled, a reduction of 50% in the total emissions would be brought about.

A significant increase in the emission control is brought about by controlling the fines dumping operation. It is estimated that the total emission control would increase from 50% to 70% if the fines were to be slurried prior to dumping. A more satisfactory method of controlling the fines may be to bag them at source in polyethylene bags. In this case, the total emission reduction is estimated to reach 87%, but the cost increased rapidly from $11,450 for the slurry system up to $17,850 for the bagging system.

From these results, it was determined that the field study emission control tests should be performed on three of the four primary sources. Soil-vegetation covers should be tested for the inactive pile, chemical stabilization should be tested for the active pile, and slurrying and bagging should be tested for the fines dumping. Aggregate crushing is very difficult to control, and is a minor contributor overall. This is because aggregate crushing is only practiced for about 6 hours per month. For this reason, no emission control tests were conducted on aggregate crushing.



Asbestos Emission Reduction

Figure 5. Least cost combinations of emission control options. (See Table 8 for code of control options.)

TABLE 8. EMISSION CONTROL OPTIONS - LEAST COST COMBINATIONS

Control Method	Capital Invest ($)	Total Annual Cost ($)	% Reduction in Emissions From: Fines Dumping	Aggregate Crushing	Active Pile	Inactive Pile	Total Emissions
8	—	3,380	—	—	—	100	12
8-1	3,700	6,180	10	—	—	100	14
8-2	4,000	6,780	20	—	—	100	16
8-5	10,000	7,480	85	—	—	100	31
8-6a	10,000	9,100	85	—	45	100	58
8-6b	10,000	8,780	85	—	27	100	47
8-6c	10,000	8,380	85	—	14	100	39
8-9	10,000	6,950	—	—	50	100	42
8-10b	10,000	7,350	—	—	80	100	60
8-5-10b	20,000	11,450	85	—	80	100	79
8-6a-10b	20,000	13,150	85	—	89	100	84
8-6b-10b	20,000	12,750	85	—	85	100	82
8-7-10b	15,000	17,850	100	—	89	100	87

Code:

1 — Water spray of fines dumping
2 — Water plus surfactant at fines dumping
5 — Water slurrying of fines prior to dumping
6a — Chemical binder (0.25%) with water slurrying
6b — Chemical binder (0.20%) with water slurrying
6c — Chemical binder (0.10%) with water slurrying
7 — Bagging of fines
8 — Soil-vegetative control of inactive piles
9 — Water spray on active pile
10b — Chemical stabilize active pile once per month

SECTION 6

FIELD TEST PROGRAM

PROGRAM DESIGN

A field test program was developed to evaluate the emission control options selected on the basis of the technical and cost effectiveness evaluation. Under the terms of the contract, only one or two options were to be selected for the field demonstration. The options considered, evaluated, and selected for study are shown in Table 9. Two options were selected for studying the control of emissions from fiber dumping -- containerization and slurrying. Two further options were selected for the study of waste pile stabilizing -- chemical binding for active piles and soil and vegetative cover for inactive piles. No control option was applied to the crushing* and leveling operation because although obvious high emissions were created, they were only created for very short periods of time and thus they were expected to make the smallest contribution overall.

Tests were conducted at the Johns-Manville asbestos cement pipe plant located at Denison, Texas, 60 miles north of Dallas. The on-site location offered the advantages of reasonable site security, easy haulage of waste material, availability of soil for pile coverage, and the availability of labor on a daily basis to maintain the piles and perform periodic tests.

Field tests were performed to obtain data on:

- The asbestos background emissions
- The emission control of the transfer operations at the dump
- The emission control and the stability of the treated waste piles

Field tests were started in August 1975. Initially, measurements were made to establish the background level of the asbestos emissions in the general area. On completion of the background monitoring tests, work commenced on the building of three small-scale asbestos cement waste piles. Piles, each 10 m in diameter, were treated, one with a chemical binder, a second was covered with soil and vegetated, while a third was left alone as a control pile. The chemically treated pile is shown in Figure 6. The soil-revegetation covered pile can be seen in Figure 7. The piles were

---

* A minor portion of pipe (1-5%) was crushed within the plant in an enclosed system; this material was recycled within the manufacturing process.

TABLE 9. EMISSION SOURCES AND CONTROL OPTIONS

Possible Control Options	Fines Dumping	Aggregates Crushing and Leveling	Active Pile	Inactive Pile
Granulation	✓		✓	✓
Containerization	Ⓢ		✓	✓
Spray wetting	✓	✓	✓	✓
Foaming	✓	✓	✓	✓
Slurrying	Ⓢ			
Chemical stabilization			Ⓢ	✓
Landfill operation			✓	✓
Soil and vegetation cover				Ⓢ
In-plant crushing		✓		
Reuse, in-plant and others	✓	✓	✓	✓

✓ Options considered.

Ⓢ Options selected for field test evaluation.

Figure 6. Chemically treated pile (No. 1)
Chemical stabilizing agent diluted in
drum with water and applied on
pile with a sprinkler.

Figure 7. Soil-vegetation covered pile (No. 2) Shown just after seeding. Straw used to protect seeds from blowing sand and to conserve soil moisture.

completed in August 1975 and were monitored to assess their stability at regular intervals for a period of seven months, ending in March 1976.

Once the long-term stability tests had been initiated on the small-scale test piles, attention was directed to measuring the emissions from dumping, crushing, and leveling operations at the active site. The reject pipe at the dump is shown in Figure 9. Tests were conducted on the existing active site since it was anticipated that the emission levels to be monitored would be considerably in excess of those established as the background level at the dump. The tests at the active dump site were conducted during September 1975.

BACKGROUND EMISSION MEASUREMENTS

It was necessary to make a site survey in the general area of the Johns-Manville, Denison plant to establish the asbestos background emission levels. Measurements were made using high-volume samplers fitted with 0.8 μm pore sized membrane filters. The filters were examined for asbestos using optical and electron microscopes and also atomic absorption chemical analysis (AA), as will be detailed later in this section. Measurements were made both upwind and downwind of the plant using six samplers operating simultaneously as shown in Figures 9 and 10. Sampling stations 1 through 4 were located on the premises of the plant. Station 5 was placed in Munson Park, about 4.8 km (3 mi) south of the plant dump. Station 6 was set up 2.0 km (1-1/4 mi) north of the dump in "Dutch" Chastain's backyard. The six stations were run simultaneously on two consecutive days. On a separate occasion, two more hi-vol stations were set up and simultaneous samples were collected some distance from the plant, upwind at Grayson County Airport, 17 km SW, station 30, and downwind at Platter, Missouri, 9.6 km N, station 29.

Further sampling was undertaken using two real-time particulate monitors -- the Royco light scattering particle counter Model 225 which is responsive to particles in the 0.3 to 15 μm size range, and a Gardner condensation nuclei counter (CNC) which is responsive to particles in the 0.002 to 1 μm size range. These latter two instruments do not distinguish between asbestos particles and other particulate matter; their use was restricted to building up information on the sources of particulates in the plant area. Their advantage is that they have a virtually instantaneous readout which enables large number of samples to be taken. This is in contrast to the high volume samples for which each single sample took one day to collect and several days to analyze.

TRANSFER OPERATION EMISSIONS

General

Fugitive emissions from asbestos waste dumping activities and from crushing and leveling operation were measured at the dump site. High volume samplers with 0.8 μm membrane filters were used to collect emission samples. A Royco light scattering particle counter was used to obtain a real-time monitoring of the emission cloud.

Figure 8. Reject pipe at the dump ready for crushing with bulldozer. Previously crushed aggregates can be seen in background.

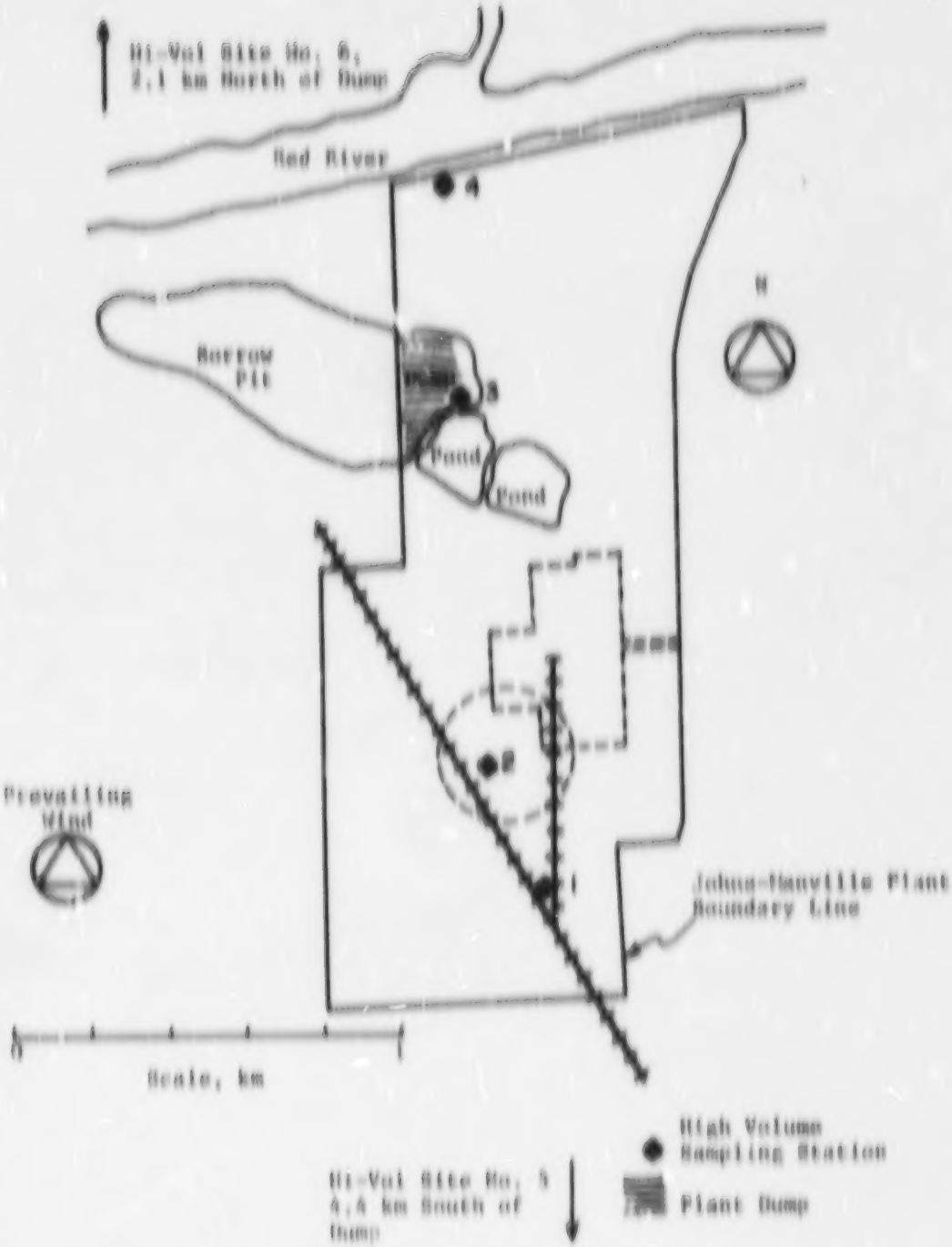


Figure 9. High volume sampler stations for area survey at Johns-Manville plant, Denison, Texas.

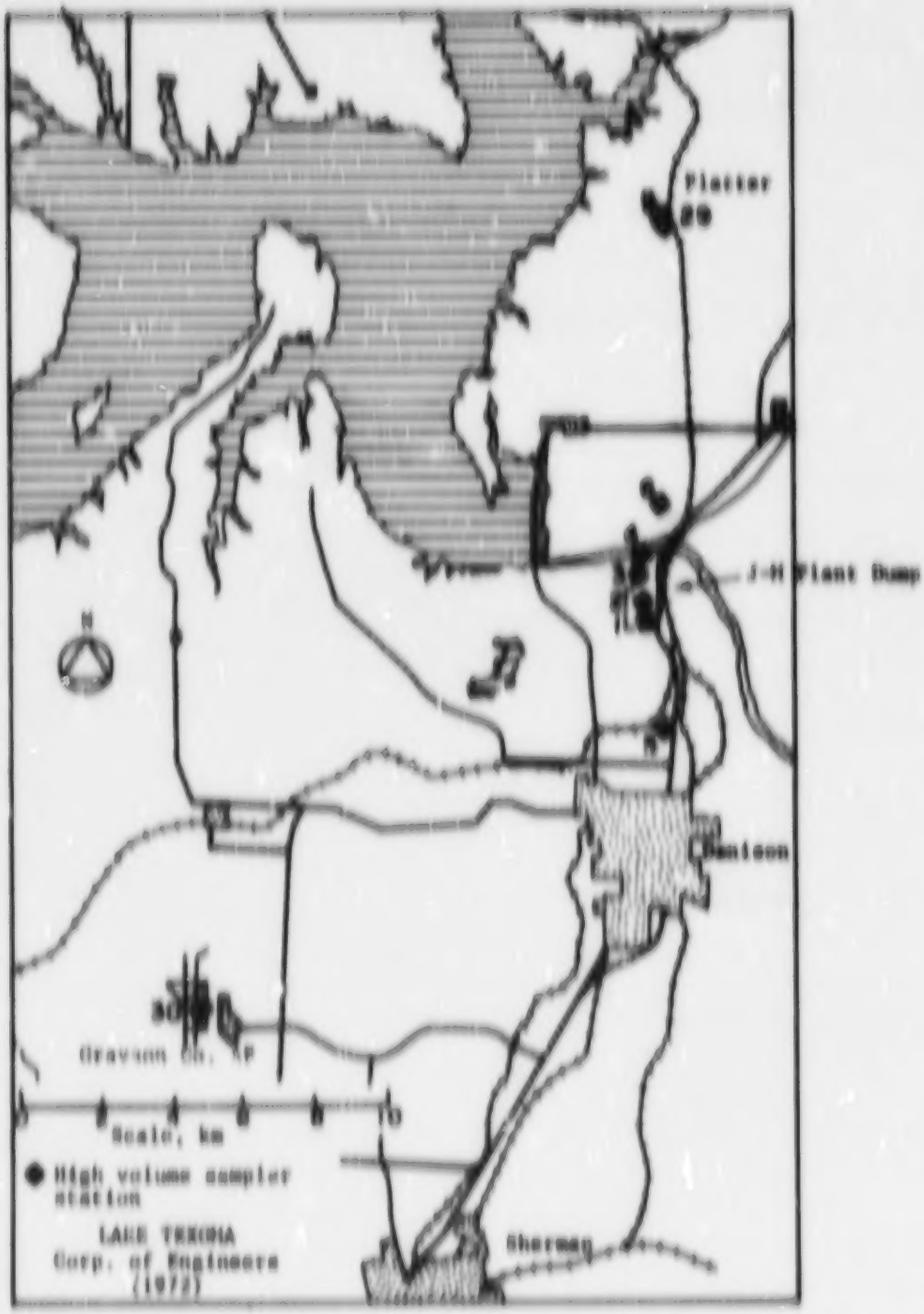


Figure 10. Location of high volume sampler stations for survey in general area of Johns-Manville, Denison, Texas.

High volume samplers were located at stations 21 through 28, as shown in Figure 11. They were erected at a height of 1.5 meters, both upwind and downwind of the source each day. Background measurements were taken with no dump activity in order to establish the base line emission levels. It was found that a reasonably constant, relatively low-level of emissions was present. Samples were then taken while separate transfer activities were carried out, such as:

- Dumping of fines uncontrolled
- Dumping of fines in slurry form
- Dumping of fines contained in plastic bags
- Crushing of waste pipes
- Leveling of asbestos waste material

Emissions from Fines Dumping

Dumping of asbestos cement waste fines created a visible emission cloud. In order to assess the effect of the control on these emissions, a series of tests were conducted. An area of the dump was leveled and was well wetted down. Onto this area, a 450 kg (1,000 lb) load of asbestos cement fines was dumped. A Royco light scattering particle counter was placed downwind from the source and the sharp rise in the particle count rate from the background level was monitored on a chart recorder as the dust cloud passed across the sampling station located 10 m downwind from the dump.

A series of tests were then made as slurries of asbestos cement fines and water, with compositions ranging between 30% to 50% by weight of fines, were dumped onto the waste pile which had been leveled and wetted. The slurries were made in a concrete mixer of 0.8 m^3 capacity. Slurries in the range of 30% to 42% appeared to offer the most desirable handling properties although all of the mixtures appeared to be very effective in controlling the emissions.

Bagging of the asbestos cement fines as a means of controlling the emissions was tested. Polyethylene bags with a wall thickness of 0.075 mm (3 mil) and a capacity of 114 liters (30 gal) were filled with 14-16 kg (30-35 lbs) of fresh dry fines and then sealed. Thirty bags were loaded into an open hopper car, taken to the waste pile, and dumped. The emissions during this procedure were monitored as before, using the Royco particle counter.

It should be noted that no attempt was made to take high volume air samples during the fines dumping tests. This is because the dust cloud was of very short duration (usually about 30 seconds) and thus they were not suitable for extended period emission collection.

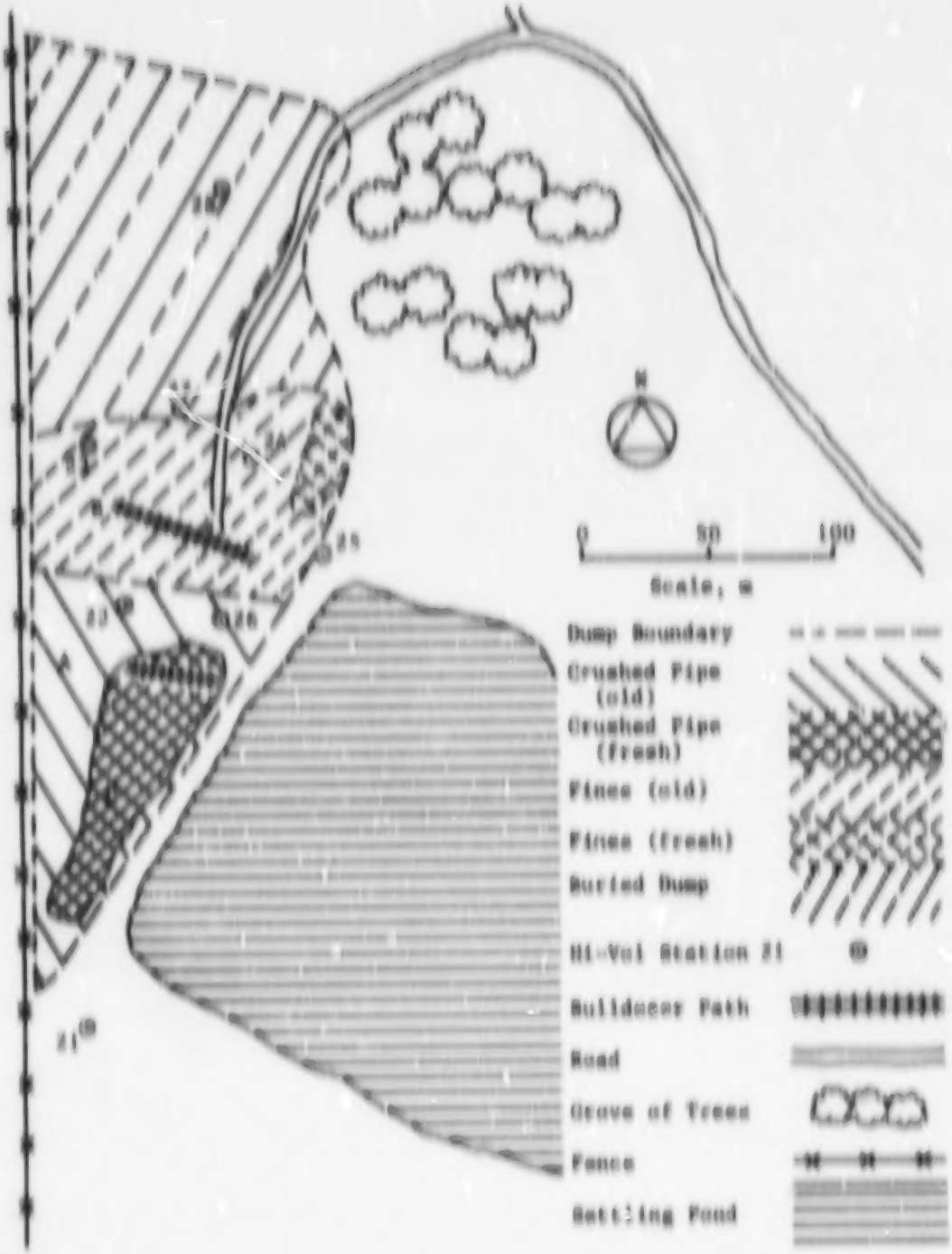


Figure 11. High volume sampling stations at the plant dump, Johns-Manville, Denison, Texas.

Emissions from Crushing of Asbestos Cement Pipe

At the plant, a bulldozer is used to crush the waste asbestos cement pipe into a more compact form. For the purposes of the present study, an Allis-Chalmers bulldozer (Model HD-16), having a total weight of 20.4 metric tons, was used. The bulldozer was operated in a path perpendicular to the direction of the wind. Within the path of the bulldozer, pipes were placed to be broken-up in a manner which replicated the normal periodic pipe crushing activities at the plant.

A Royco light scattering particle counter was placed downwind and perpendicular to the path of the bulldozer. Using a chart recorder, the emission level was monitored as the bulldozer made a pass along the path, pushing pipe in front of its tracks with its blade and running over the pipe to crush it.

Six high-volume air samplers fitted with 0.8 μm membrane filters were placed in an upwind-downwind array to monitor the emissions over an extended time period. The positions of the high-volume samplers numbers 21 through 26 and the path of the bulldozer marked as A are shown in Figure 11. The samplers were located at distances of 30 to 100 m from the center of the path taken by the bulldozer.

Emissions from Leveling of Asbestos Cement Waste

Leveling of the asbestos cement waste pile is achieved by using the blade of the bulldozer as a scraper. Fine material is pushed into the voids in the crushed pipe sections and the mixture is scraped level. In order to measure the emissions from this operation, a series of experiments, similar in nature to those adopted for the pipe crushing tests, were developed. Waste material was leveled along the path marked B on Figure 11. The path was perpendicular to the wind direction. An array of six high-volume samplers were located at sampling positions numbers 21, 23, 24, 25, 27, and 28. A Royco particle counter was located at a distance of 45 m downwind from the mid-point of the leveling path.

STABILIZATION OF WASTE PILES

Asbestos Entrainment from Waste Piles

The ease with which asbestos particles might be released and emitted into the atmosphere is closely related to properties of the waste and the manner in which some of these properties change with time. Those effects which contribute to the erosion of the soil by the wind are of particular concern.

Wind erosion transports the soil in three modes, depending on particle size:[24,28]

Transport Mode	Particle Diameter, mm
Suspension	<0.1
Saltation	0.05 to 0.5
Surface Creep	0.5 to 1.0

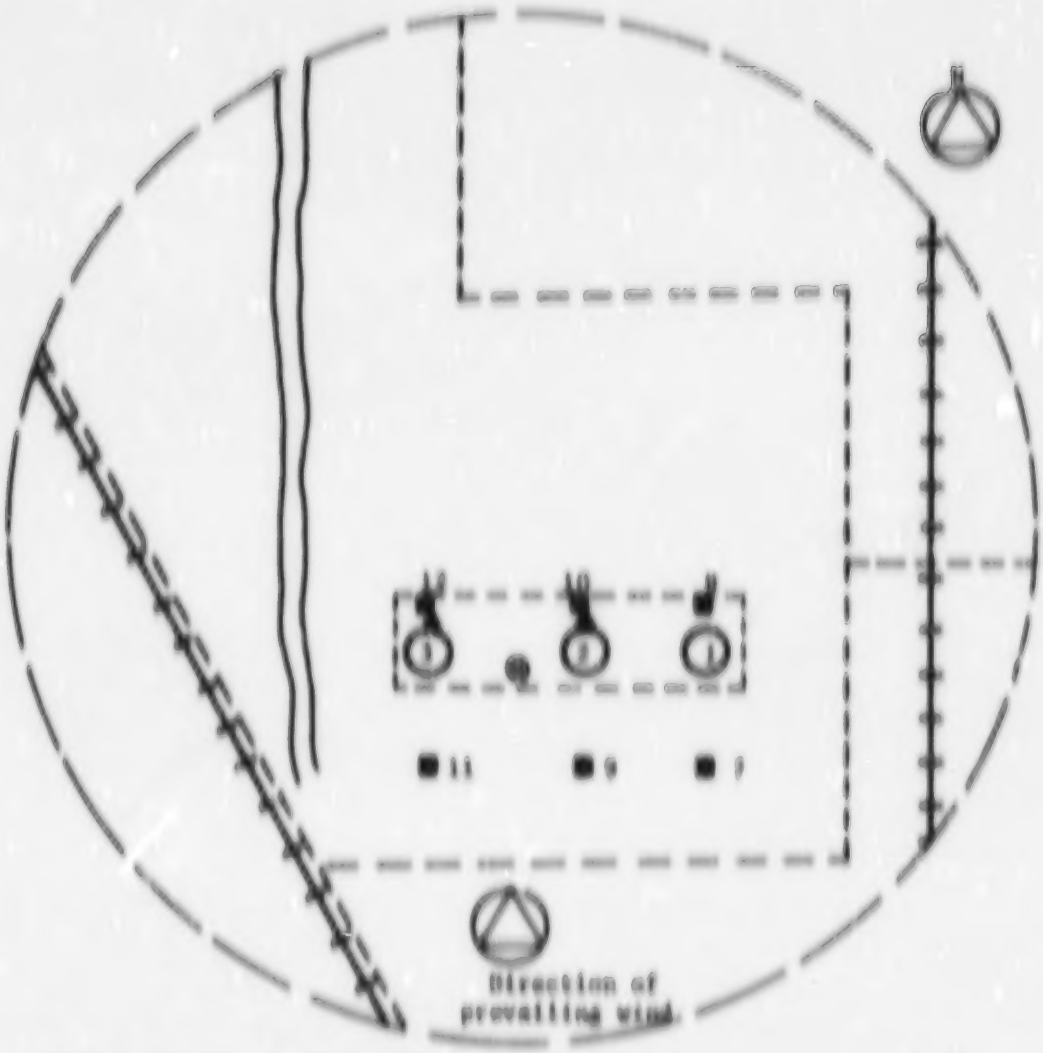
Saltation is the active soil mover. Particles in the 0.05 to 0.5 mm range are directly dislodged by the surface turbulence of the wind and undergo active bouncing and jumping movements which dislodge other particles and result in a cascade of soil movement. Saltation accounts for up to 75% of the soil movement. Much of the movement of particles in the other size ranges is eliminated by reducing the number of particles which participate in the saltation process. The larger grains are too heavy to be directly dislodged and their movement results primarily from saltation grain impact. The finer particles are more tightly bound to the surface and are not readily dislodged by the wind action alone. However, once they are emitted, they remain suspended for long periods of time and can be transported great distances.

From the above, it can be seen that in order to reduce the entrainment of asbestos, it is necessary to prevent the saltation particles from freely moving. In this study, stabilization was attempted in two ways: first, a chemical binder was added to lock the particles together, and second, a vegetated soil layer was used to cover the free surface of the asbestos waste.

Construction of Test Waste Piles

Three small-scale test piles were constructed from waste asbestos cement pipe and fines materials which would ordinarily have been deposited on the main dump. The test piles were located on the far side of the plant from the plant dump and on the upwind side in terms of the prevailing wind, as shown circled in Figure 9 and enlarged in Figure 12. The piles were arranged in such a manner that a line drawn through the piles was perpendicular to the prevailing wind. Each pile was 10 m in diameter and each pile was separated from its neighbor by a distance of 50 m. The nearest building of the plant was about 150 m from the closest pile.

Initially, 38 m^3 of broken pipe were deposited on each of the three pile sites. Fine material in the ratio of 9:1, pipe to fine material, was then dumped on top of the broken pipe material, giving a total of 4.6 m^3 of fine material per test pile. In the case of pile number 2, which was to be soil covered, an additional 2.3 m^3 meters of fines were dumped because the 4.6 m^3 was not sufficient to fill the voids in the broken pipe pieces. A level surface was required on this pile to enable an even soil cover to be placed on the top surface.



Weather Station
Hi-Vol Station
Water Tap
Control Pile
Soil-vegetation Covered Pile
Chemically Stabilized Pile

0 50 100
meters

Barbed Wire Fence
Railroad Tracks
Dirt Road

Figure 12. Field test pile site, Johns-Manville plant, Denison, Texas.

A bulldozer was used to shape and consolidate the piles. The average height was 0.6 m and the sides were given a 4 to 1 slope. The top surface was nearly flat with a diameter of about 5 m.

The site selected for construction of test waste piles was on a soil fill area. The fill came from a cut within the plant area and was a mixture dominated by somewhat sandy strata mixed with clayey surface soil. The moderately dense vegetation on this site included black medic, perennial ryegrass, tall fescue, weeping lovegrass, bermuda blackberries, cottonwoods, and several species of weedy forbs which were not identified.

Chemical Stabilization of the Waste Pile

It was reported in Section 4 that a large number of chemical stabilizers are available. From the available stabilizers, one had to be selected for the field test. Some of the desirable characteristics of chemical stabilizers in terms of the present study are listed in Table 10. From prior experience at IITRI, a short list of candidate stabilizers was selected since an exhaustive selection process was not feasible. These materials were tested for durability by forming small cones of asbestos waste and impregnating them with the stabilizer at various concentrations. The impregnated cones were then dried and subjected to simulated rainfall for various time periods. The cones were then tested for strength by measuring the compressive load required to cause the cone to collapse. The stability of the cones was also measured in a separate way by measuring the quantity of organic (stabilizer) and inorganic (asbestos-cement) material leached from the cones by the action of the simulated rainfall.

An example of the results obtained are given in Table 11. It is seen that COHERES (Golden Bear Division, Witco Chemical Corporation, Oildale, California) and ELVANOL (Du Pont Chemical Company, Delaware) both performed well. Although ELVANOL scored better than COHERES in each of the tests, application of COHERES is much easier than ELVANOL and it was selected for use in the field test for that reason. COHERES is purchased in ready to mix form and can be stored indefinitely. It can be easily diluted to the desired application strength at the site just prior to use with no special equipment or care. ELVANOL is sold as a powder which must be slurried in cold water and then heated to about 200°F with constant stirring. It dissolves and forms a stable solution at that temperature. Solution strengths of up to 25% can be prepared in this manner but stable solutions are only formed at less than 10% concentrations. At the higher concentrations, the viscosity of the solution is high and could interfere with easy dispersion and soaking in of the stabilizer into the soil.

File 3 was treated with COHERES in the ratio of one part of COHERES to four parts of water. The diluted solution was applied with an oscillating sprinkler using a liquid pump. The distribution of water from the sprinkler (Dial-A-Rain, Model 055A, L. R. Nelson Corp., Peoria, Illinois) was tested with a series of open top cans. The cans were placed in line with and perpendicular to the direction of the sprinkler oscillation. Under very low wind conditions, a remarkably uniform coverage was obtained over an 11 m x 11 m area.

TABLE 10. DESIRABLE STABILIZER PROPERTIES

- Low application cost
- Water soluble
- High bondability to the particles under consideration
- Long life and stability
- Resistant to heat and cold
- Non-phytotoxicant
- Biodegradable
- No water pollution problems from drainage water
- Easy to mix and apply
- Effective in low dilutions

TABLE II. EFFECT OF CHEMICAL TREATMENTS ON MECHANICAL PROPERTIES OF ASBESTOS WASTE AND RETENTION OF TREATMENTS AFTER SIMULATED RAINFALL

Treatment	Compressive Strength, lb		Removal by Water Spray, mg/Sample	
	Before Rain	After Rain	Organic	Inorganic
Water	4.0			9.2
Vinsol	3.3	7.0	16.7	58.5
DeFloc	7.5	11.0	38.1	40.6
Elvanol 71-30 (PVA)	9.7	47.5	4.25	1.1
Cellosize	11.5	33.5	24.0	6.5
Elvanol L	2.5	4.0	110.0	29.36

The amount of COHERREX applied was based on the coverage recommended by Dean[16] for effective stabilization of mine and mill wastes against the ravages of both wind and rain. COHERREX concentrate was applied at the rate of 0.45 l/m^2 (0.1 gal/yd^2).

Vegetative Covering of the Waste Pile

Waste pile number 2 was covered with a 30 cm layer of sandy loam. The soil was then broadcast fertilized with a locally purchased lawn fertilizer (Vertagreen, Texas Lawn Fertilizer 10-10-5 with iron and sulfur, USS). The soil was fertilized at the rate of 13.4 g/m^2 (120 lbs/acre) of nitrogen, 13.4 g/m^2 (120 lbs/acre) of phosphorus pentoxide, and 6.7 g/m^2 (60 lbs/acre) of potassium oxide. The soil cover was then worked lightly with a disc to mix in the fertilizer. A preliminary testing with the disc showed that it could be easily controlled so that the soil surface would be penetrated no more than 15 cm. A mixture of K-31 tall fescue, weeping lovegrass, and black medic was then broadcast seeded at the rate of 2.25, 1.12, and 1.12 g/m^2 (20, 20, and 10 lbs/acre), respectively. This represented a mixture of species similar to those presently growing in the area.

An oat straw mulch was then spread on the pile surface at the approximate rate of 0.45 kg/m^2 (4,000 lbs/acre). It was lightly disced to crimp the straw into the soil to provide protection for the establishment of the vegetative covering.

An initial application of 6.4 cm (2-1/2 in.) of water was used to moisten the soil cover. An additional 0.85 cm (1/3 in.) of daily irrigation was applied for a three week period to insure germination and initial establishment. The plot water was continued twice weekly, putting on an inch of water each time. The watering was continued until the Fall rains began. The rain gauge on the test site was used to determine the amount of supplemental watering required.

The plot was refertilized six weeks after initial application to make up for leaching of nitrogen which occurred during the initial establishment period. The seeds germinated within the first week and easily took root in the sandy loam which by itself contained very little natural nutrients.

Waste Pile Test Schedule

A schedule of tests and measurements to be made on the three waste piles was set-up as shown in Table 12. The tests involved the monitoring of the weather on a local scale, measurement of the emissions by high volume sampler, and a series of tests designed to measure the stability, or structural integrity, of the piles.

SAMPLE COLLECTION AND ANALYSIS PROCEDURES

Collection of Emissions in the Ambient Air

Ambient air samples were collected on membrane filters with high-volume samplers. Millipore membrane filters (Type AA) with a 0.8 μm pore diameter

TABLE 12. WASTE PILE TESTS AND MEASUREMENTS

Tests and Measurements	File No.* 1	2	3
A. Continuous			
1. Weather station (wind speed, wind direction, temperature)			
2. Rainfall (raingage)			
B. At weekly intervals			
1. (Hi-vol samples) ambient air emission	X	X	X
2. Soil surface moisture	X		X
3. Vegetation coverage (during first two months) (visual estimate)		X	
C. At three month intervals			
1. Pile surface grain analysis (wet sieve analysis)	X		X
2. Consolidation and surface reduction (settlement plate)	X		X
3. Penetration resistance (Proctor penetrometer)	X		X
4. Density of pile surface (Shelby tube samples)	X		X
5. Channeling (visual estimate)	X	X	X
6. Soil pH (pH meter)		X	
7. Chemical stability treatment (carbon analysis)			X

* Pile No. 1 -- control pile, untreated
Pile No. 2 -- soil-vegetation covered pile
Pile No. 3 -- chemically stabilized pile

cut to 20.3 cm x 25.4 cm with a sample collection area of 406 cm were used. Source emissions were determined from simultaneous upwind and downwind sample collection. For the test piles, six hi-vol stations were set up to collect upwind and downwind particulate samples simultaneously on a weekly basis. Each upwind station was located 40 m south of each pile and each downwind station was located 10 m north of each pile, as shown in Figure 12. Meteorological information was obtained continuously from a recording weather station, MRI Model 1072, located in the vicinity of the test piles.

Particle Counters

Two particle counters with complimentary particle size detection ranges were used in the field tests. The condensation nuclei counter (CNC, Gardner Associates, Inc.) is a portable instrument which detects low to moderate levels of particle concentrations in the size range between 0.0015 to 1.0 μm. This instrument was used in making the background survey of the area.

The Royco Model 225 aerosol particle counter is a bench top instrument which was powered by an AC generator and used as a mobile unit. Both digital and analogue output plug-in modules are available. For the field work, the analogue output connected to a DC recorder was preferred. The Royco counter will measure aerosol particles of 0.3 μm diameter and larger in concentrations of up to 1.5×10^9 particles/m^3 (10^8 particles/ft^3). The Royco counter was selected to estimate the effectiveness of control measures used in dumping.

Neither instrument distinguishes between fibers and other particles. However, they both offer real time particle concentration measures and are useful for estimating relative levels of particulates in the ambient air.

Optical Microscope Counts

A Leitz Orthoplan microscope fitted with phase contrast optics at 500X (using 40X 0.65 N.A., objective) was used for optical microscope (OM) counting. The basis of the procedure used was that detailed by the Joint AIHA - ACGIH Aerosol Hazards Evaluation Committee.[3] Millipore filter membranes were cleared using a 1:1:1 solution of hexane, 1,1 dichloroethane, and p-dioxane (see Section 8-D).

Two slides were prepared from each membrane filter examined; a minimum of 100 fields on each slide were examined. A field has a (50 x 100) μm^2 area represented by the boundaries of a Porton eyepiece reticle.

Obvious non-mineral fibers, such as spores and pollens, have been excluded from the fiber counts. Fibers are defined here as particles with aspect ratio $\geq$ 3 to 1. The minimum fiber length counted was 1.5 μm.

Electron Microscope Analysis

A JEOL 100C electron microscope (EM) was used to examine fibers which were shorter than 5 μm in length. The fibers collected on a membrane filter were transferred to an EM grid. A membrane filter section was cut slightly

larger than 3 mm in cross section from the center of each filter and placed particle side down on a 3 mm carbon coated EM grid. The filter covered grid was placed in a EPFA condensation washer (E.F. Fullam, Inc.) and washed overnight with acetone vapors. The solvent gently removed the filter media and deposited the collected fibers on the carbon film.

Fiber counts were made at 20,000X magnification (EM field = 0.72×10^{-4} cm^2). Fiber lengths and widths were recorded for each fiber. Random fibers in each sample were selected for crystallinity determination and for x-ray elemental analysis.

Calculation of Fiber Concentrations

The fiber concentration is calculated from the microscopic fiber count. It is assumed that the field distribution of fibers follows a Poisson distribution. The error at the 95% confidence level for a random sample with this type of distribution would be expressed by the formula

$$\text{Error} = \pm 2\sqrt{C}$$

where C is the total count for the sample examined. Based on a count of 100 fibers, then the expected error = $\pm 2\sqrt{100}$ or $\pm$ 20 fibers. In general, we have attempted to get OM counts from 200 fields for each sample.

The ambient air concentration is calculated from the microscope fiber count using the following formula

$$X = \left(\frac{\text{Fiber Count}}{\text{Fields Counted}}\right) \cdot \left(\frac{\text{Total Filter Area}}{\text{Porton Reticle Area}}\right) \cdot \left(\frac{1}{\text{Volume of Air}}\right)$$

Example: For an OM fiber count of 100 fibers in 200 fields using a 20.3 x 25.4 cm^2 (8 in. x 10 in.) filter, operating at 0.849 m^3/min (30 cfm), collected for 2 hours

$$X_{OM} = \frac{100 \text{ fibers}}{200 \text{ fields}} \cdot \frac{406 \text{ cm}^2}{5 \times 10^{-5} \text{ cm}^2} \cdot \frac{1}{102 \text{ m}^3} = 4.0 \times 10^6 \pm 0.8 \times 10^6 \text{ fibers/m}^3$$

Atomic Absorption Analysis

When its use is feasible, atomic absorption (AA) spectroscopy can be used to compliment OM fiber counts. It can be more reliable for measuring low asbestos emission levels than microscopic fiber counting. The subjective element in fiber counting is not present in AA analysis. Also, by using relatively large filter areas (100 cm^2 compared to 1 cm^2 for OM), the local concentration variations of fibers on a filter are non-existent.

For fiber counting under the optical microscope, the precision is given by $2\sqrt{C}$, where C is the fiber count in 100 reticle fields under the microscope. For a standard deviation of 10%, a count of 400 fibers/100 fields would be required. The same degree of precision would be achieved for

0.4 ppm asbestos using AA, a concentration equivalent to 6 fibers/100 fields. This is based on analysis of chrysotile with an assumed average gravimetric size of 1.0 μm diameter x 10 μm length (10:1 aspect ratio).

The sensitivity of the elemental analysis by AA was limited by the background concentration of the element used in the analysis. The background has two predictable sources. The acid solution used to dissolve the sample contributed 0.1 ppm of magnesium. The Millipore Type AA filter on which the asbestos was collected contributed an additional 0.65 ppm for 100 cm^2. The filter background concentration was proportional to the weight of the filter sampled and serves as a lower limit to the useful sensitivity of the analysis. The total background was 0.75 ppm. Assuming a minimum background concentration of 0.75 ppm ± 0.01, a 4 μg asbestos sample can be detectable to ± 10%.

Atomic absorption (AA) analysis was used to determine the concentrations (X_{AA}) of asbestos collected on the membrane filters. A Perkin-Elmer Model 360 atomic absorption spectrometer was used. Magnesium was selected as the tracer element. The use of AA to measure the asbestos emission concentration was feasible because the background levels of magnesium in the area were relatively low and constant. An emission source was identified by the difference in concentration of magnesium found in simultaneously collected upwind and downwind ambient air samples.

The method used for sample preparation was an adaption of the one in the EPA Methods Handbook.[8] The sample was prepared for AA analysis by digestion of a 100 cm^2 filter section in nitric acid. The filter section was digested to dryness on a sand bath in a covered beaker with three 5 ml portions of concentrated reagent grade nitric acid. This treatment served both to decompose the cellulosic material in the filter, as well as to dissolve the fine mineral particulates on the filter. The final residue was dissolved in 1 ml of 50% hydrochloric acid and then diluted to a volume of 10 ml with deionized water (2,000 ppm lanthanum is also added for control of phosphate interference) and submitted for AA analysis.

For samples of bulk waste from the dump, a procedure described by Perkin-Elmer[9] was followed. These samples were treated twice with 5 ml of a 1:1 HCl/HF solution to decompose the silicates in the cement. This was done in plastic beakers over a hot water bath after initial digestion with concentrated nitric acid. The final residue was redissolved in the 5% hydrochloric acid solution containing lanthanum.

The results of the AA measurements have all been converted to concentrations of asbestos in the atmosphere (μg/m^3). The atmospheric concentrations of asbestos are calculated from the magnesium concentrations in high volume filter samples using the following formula

$$X_{AA} = \frac{(C_{AA} - C_{AB}) \cdot A_{HV} \cdot V_{AA}}{T_{HV} \cdot F_{HV} \cdot A_{AA} \cdot C_{MG}}$$

where

X_{AA} = concentration of asbestos fibers in the air, $\mu g/m^3$

C_{AA} = concentration of magnesium in the AA analysis sample, $\mu g/cm^3$

T_{HV} = sampling time, min

F_{HV} = sampler flow rate, m^3/min

C_{MG} = wt. fraction of magnesium in asbestos

C_{AB} = concentration of magnesium in the filter blank, $\mu g/cm^3$

A_{HV} = total cross section area of hi-vol filter, cm^2

A_{AA} = area of hi-vol filter used in AA analysis, cm^2

V_{AA} = total volume of solution used in AA analysis, cm^3

Source Emission Rates at the Dump

Emission rates from the waste pile were calculated from both the OM fiber counts and AA analysis using the Binomial Continuous Plume Dispersion Model as detailed by Turner.[27] The technique permits prediction of emission rates from a source using measured concentrations of a downwind ambient pollutant.

A number of assumptions are made in the use of this model:

- The plume spread has a Gaussian distribution in both the horizontal and vertical planes.
- The wind is constant in speed.
- The emission rate is uniform.
- Total reflection of the plume takes place at the earth's surface.
- Diffusion in the direction of the plume travel is minimal.
- Point source extrapolations can be used to estimate the source emission rate.

For concentrations of an ambient pollutant measured at ground level from a ground level point source with no effective plume rise, the following equation can be used when samples are taken along the center line of the plume

$$Q = \frac{U}{A}$$

where

$$q = \frac{\bar{\chi}_{(x)} \cdot \pi \cdot \sigma_z \cdot \sigma_y \cdot U}{H_f}$$

so that

$$R = \frac{\bar{\chi}_{(x)} \cdot \pi \cdot \sigma_z \cdot \sigma_y \cdot U}{A \cdot H_f}$$

where

R = emission rate per unit area, $g/sec/m^2$

q = emission rate/ g/sec

A = area of source, m^2

$\bar{\chi}_{(x)}$ = measured concentration from a hi-vol sample at a distance downwind along centerline, g/m^3

σ_z, σ_y = standard deviation of plume concentration distribution perpendicular to centerline in horizontal, σ_y, and vertical, σ_z, directions at distance, x, downwind

U = velocity of wind, m/sec

H_f = hi-vol sampling time related concentration factor

Background emission rates were calculated by considering the dump to be an area source with an initial standard deviation of σ_{yo} equal to the width of the area cross section. A virtual distance, X_y, was found (see Turner's Handbook,[17] Figure 3-2) which had a σ_y value equal to σ_{yo}. Then the emission concentration at the receptor was used to calculate emission rates from a point source at a distance of $X + X_y$ upwind from the receptor.

The emission rate of a continuously emitting infinite line source can be estimated from the emissions collected at a downwind receptor. For an infinite line source which is emitting perpendicular to the wind direction, the source emission rate is expressed as

$$q = \frac{\sqrt{2\pi} \cdot X \cdot \sigma_z \cdot U}{2} \cdot \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

where

q = the source strength per unit source length

H = the source height

X = the emission concentration at the receptor

and the other terms are the same as for the previous equation. Due to mutual compensation of lateral dispersion from adjacent segments, the horizontal dispersion parameter, σ_y, does not appear in the equation.

For the ground level infinite line source, such as a highway, the concentration at the receptor becomes

$$Q = \frac{\sqrt{2\pi} \cdot X \cdot \sigma_z \cdot U}{2}$$

In the field tests of crushing and leveling operations, a finite line source approximation was used. The ground level finite line source emission rate was estimated from the emissions collected at a ground level receptor as

$$q = \frac{\sqrt{2\pi} \cdot X \cdot \sigma_z \cdot U}{2} \cdot \int_{P_1}^{P_2} \frac{1}{\sqrt{2\pi}} \cdot \exp\left(-\frac{P^2}{2}\right) dP$$

where

$P_1 = Y_1/\sigma_y$, and $P_2 = Y_2/\sigma_y$

The wind orientation must be perpendicular to the direction of the line source. The line source is considered to extend from Y_1 to Y_2 where $Y_1 < Y_2$. The values for the integral are available from tabulations found in the statistical table.

The source emission rate, Q, is proportional to the line source length and is expressed as

$$Q = p \cdot q$$

where p is the bulldozer path length.

The emission rate can also be estimated from the measurement of particle losses from a pile surface using the equation

$$E = \frac{A_f \cdot S_f \cdot D \cdot L}{T}$$

where

E = the emission rate of a unit area of surface

A_f = asbestos fraction in waste

S_f = fraction of surface material lost

D = density of surface layer

L = thickness of surface layer

T = time duration of emission

Example: The effect of a 1% loss of particles in the top 1.27 cm layer of a surface with 0.8 g/cm^3 bulk density and containing 12% asbestos is calculated when the loss takes place uniformly over a period of six months

$$E = \frac{(0.12)\ (0.01)\ (0.8\ g/cm^3)\ (1.27\ cm)\ (10^4\ cm^2/m^2)}{1.56 \times 10^7\ sec}$$

$$E = 0.8 \times 10^{-6}\ g/sec/m^2$$

SECTION 7

FIELD TESTS RESULTS AND DISCUSSION

BACKGROUND ASBESTOS EMISSIONS

The results obtained when the high volume filter samples were examined by both optical microscopy and atomic absorption are given in Table 13. It can be seen that (a) the emissions on the two separate days are similar, (b) the emissions are similar in magnitude both upwind and downwind from the plant, and (c) the emissions are present at considerable distances from the dump.

In Figures 13 and 14, the emission concentrations have been plotted as a function of distance from the plant for the optical microscopy data and the atomic absorption data, respectively. In Phase I of this study[11], some preliminary samples taken in close proximity of several waste dumps indicated a similar trend. The result is theoretically predicted, over the long term, by application of the Climatological Dispersion Model (CDM)[8]. This model was used in Phase I and it is interesting to display here in Figure 15 the asbestos concentrations predicted by the model. Emission concentrations are predicted both upwind and downwind as a result of all of the varying directions taken by the wind over the long term.

Although the concentration levels are somewhat different, there is a remarkable similarity in the form of the sampled data and the theoretical predictions. This result is of practical significance to the Environmental Protection Agency and much more data should be collected in order to better understand the dispersion of asbestos from industrial asbestos plants.

Background particle counts were measured throughout the plant area using a condensation nuclei counter (CNC). A summary of these results is given in Table 14. It can be seen that the particles counted near to the scene of vehicular traffic, that is, near to the highway and in the immediate plant buildings, were far in excess of those found in other areas. The CNC is not specific for asbestos and will respond to all particles acting as nucleation sites in the range 0.0015 μm to 1.0 μm. Since the emissions from the vehicular activity swamped all other sources, the results could not be further utilized in this study.

EMISSIONS FROM THE TEST PILES

High volume samples were placed 50 m upwind and 10 m downwind from each of the three test piles. Samples were collected on a weekly basis. For purposes of comparison, a selection of samples were analysed which had

Table 13. BACKGROUND ASBESTOS CONCENTRATION, UPWIND AND DOWNWIND OF THE JOHNS-MANVILLE PLANT DUMP, DENISON, TEXAS; RESULTS OF OM FIBER COUNTS AND AA ELEMENTAL ANALYSIS

Date	Hi-vol Station No. (Filter No.)	Distance from Dump, km	Asbestos Emissions[1] E_{OM} Fibers/m^3 x 10^{-4}	E_{AA} ng/m^3 x 10^{-3}
8-06-75	5	4.44, upwind	2.8	1.54
8-06-75	1	1.26, upwind	3.2	0.87
8-06-75	2	0.87, upwind	3.7	1.04
8-06-75	3	0.00	3.0	1.21
8-06-75	4	0.55, downwind	2.4	1.54
8-06-75	6	2.06, downwind	1.3	0.77
8-07-75	5	4.44, upwind	0.88	0.88
8-07-75	1	1.26, upwind	1.51	0.88
8-07-75	2	0.87, upwind	1.93	1.38
8-07-75	3	0.00	5.2	3.02
8-07-75	4	0.55, downwind	1.1	0.88
8-07-75	6	2.07, downwind	1.04	0.80
9-18-75	30	17.0 , upwind	1.28	0.0
9-18-75	29	9.6 , downwind	1.12	0.0

[1] E_{OM} = optical microscope fiber counts, fiber length > 5 um.

E_{AA} = chrysotile asbestos concentration by Atomic Absorption Analysis for magnesium.

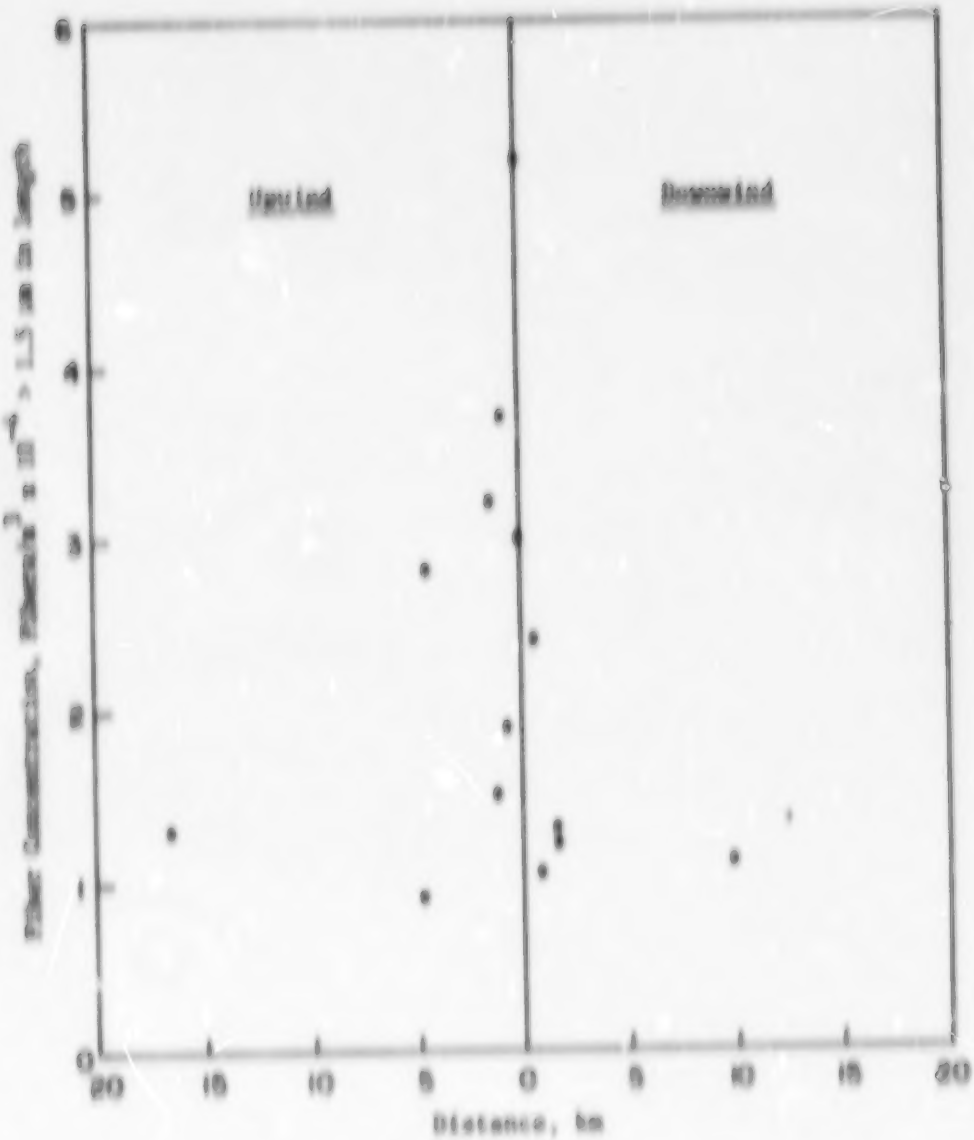


Figure 13. Distribution of fibers > 1.5 μm in length, upwind and downwind of the plant.

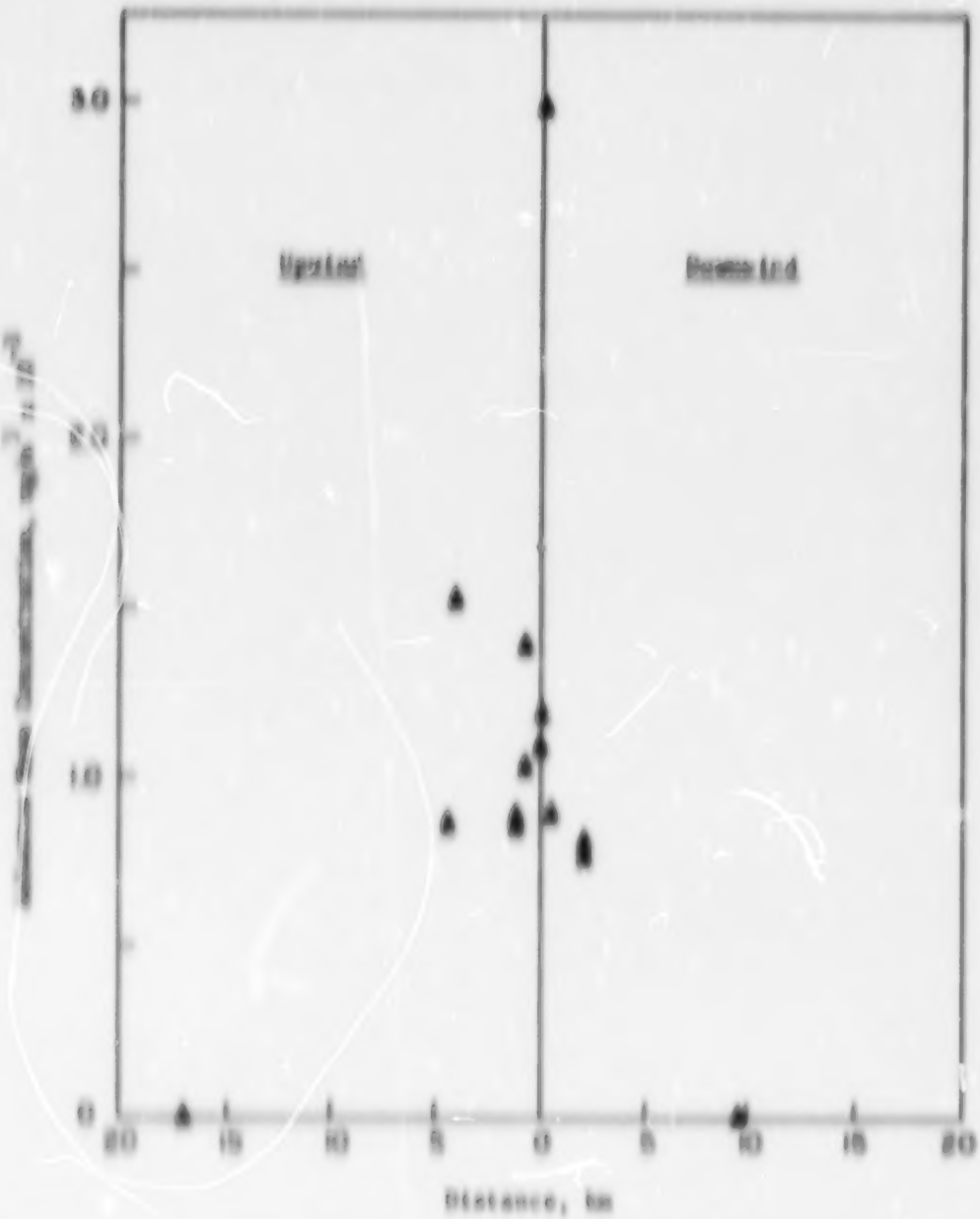


Figure 15. Distribution of asbestos mass concentration upwind and downwind of the plant.

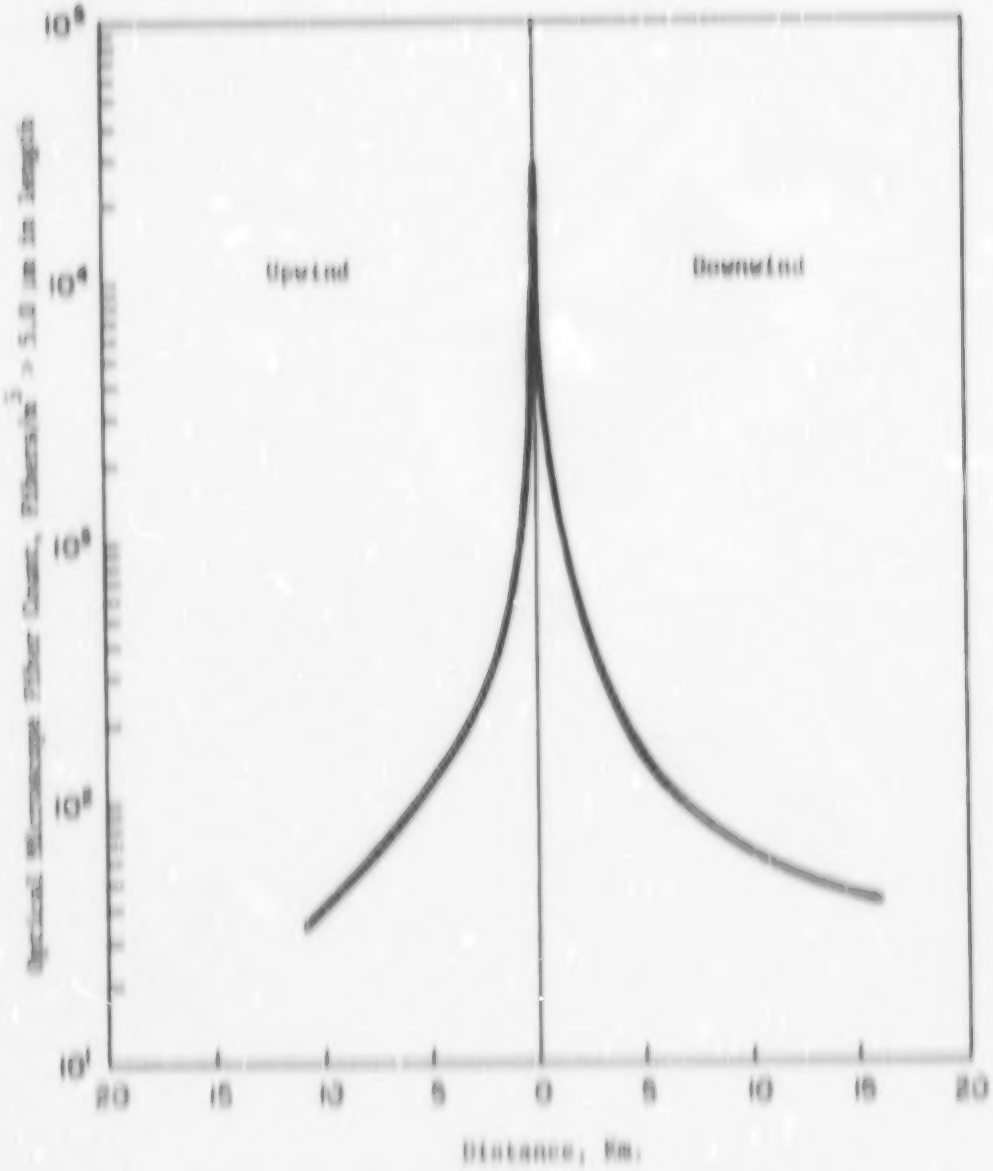


Figure 15. Asbestos concentration distribution upwind and downwind of plant as predicted by Climatological Dispersion Model.

Table 14. PLANT AREA BACKGROUND PARTICLE COUNTS MEASURED BY CONDENSATION NUCLEI COUNTER

Sampling Location	CNC Counts x 10^{-15}, p/m^3	
	Date: August 9, 1973	Date: August 22, 1973
Next to Highway	260	540
In Plant Area	29	21
At Dump	11	14
Field 300 m S. of Plant	9	43
Field 300 m N. of Plant	14	25
Wind Direction and Speed	NE-S 0-3 km/hr	E 1.6-3.2 km/hr

been collected under similar meteorological conditions (that is, similar wind speed and direction, and similar soil moisture and time periods between precipitation and sampling). Typical results of the optical microscope (OM) analysis of these filters are given in Tables 15 through 18.

It is immediately apparent from these tables that the differences between the upwind and downwind samples are either very small or non-existent. In Figure 16, all of the upwind samples taken on given dates and all of the downwind samples have been plotted with their mean values and standard deviations. It can be seen that the standard deviations show considerable overlap. Using the null hypothesis, the averages were subjected to the statistical "t" test to determine if a significant difference did in fact exist.

The measure, t, for this particular application can be formulated as follows

$$t = \frac{\bar{X}_d - \bar{X}_u}{S} \sqrt{\frac{n + m}{n + m}}$$

where $\bar{X}_d$ and $\bar{X}_u$ are the average downwind and upwind concentrations sampled at the same time. m and n are the degrees of freedom for the upwind and downwind sets and are each equal to one less than the number of samples, h, in each set. S is the standard deviation of the combined set of the upwind and downwind samples. S is calculated from

$$\left(\frac{\sum_{j=1}^{j} \sum_{i=1}^{i} (S_i - \bar{X}_j)^2}{\sum_{j=1}^{j} (h_j - 1)} \right)^{1/2}$$

i is the number of samples in a set and j is the total number of sets.

In Table 19, the calculated t values are compared with the values of $t_{0.10}$, which, for normal distribution of samples, will be exceeded only 10% of the time if the samples are all from the same population. The fact that the t values in every case are less than the $t_{0.10}$ values means that the difference between the average sample concentrations, $\bar{X}_d$ and $\bar{X}_u$ are not significant at the $t_{0.10}$ level.

It is concluded from these results that the emissions from the small test piles are too low to be monitored. Three reasons why they cannot be monitored are:

- the general asbestos background level in the vicinity of the plant is relatively high even upwind from the source
- the monitoring instruments for asbestos are not sufficiently sensitive
- the total emissions from the small test piles are very low

Table 15. OPTICAL MICROSCOPE MEASUREMENT OF FIBER EMISSIONS FROM STATIC ASBESTOS CEMENT WASTE TEST PILES, SAMPLED ON AUGUST 21, 1975

Test Pile (No.)	Hi-vol Station (meters)	OM Concentration x 10^{-4}, fibers/m^3 Fiber Length >1.5 μm	>5 μm
Control (1)	Upwind (40)	3.6	0.24
Control (1)	Downwind (10)	3.3	0.39
Soil Cover with Vegetation (2)	Upwind (40)	5.0	0.13
Soil Cover with Vegetation (2)	Downwind (10)	4.4	0.18
Chemically Treated (3)	Upwind (40)	(15.3)[a]	(1.50)[a]
Chemically Treated (3)	Downwind (10)	9.3	0.34

Wind Direction:	S-SE
Wind Speed:	15.7 km/hr (8-10 mph)
Hi-vol Height:	1.67 m (5.5 ft)
Temperature:	26.6°-21.1°C (80°-70°F)
Sampling Interval:	~2 hrs
Sampling Volume:	~102 m^3 (3,600 ft^3)
Soil Moisture:	light rain

[a] Hi-vol disturbed.

Table 16. OPTICAL MICROSCOPE MEASUREMENT OF FIBER EMISSIONS FROM STATIC ASBESTOS CEMENT WASTE TEST PILES, SAMPLED ON OCTOBER 13, 1975

Test Pile (No.)	Hi-vol Station (meters)	OM Concentration $\times 10^{-4}$, fibers/m^3 Fiber Length >1.5 μm	>5 μm
Control (1)	Upwind (40)	7.1	0.56
Control (1)	Downwind (10)	10.7	1.28
Soil Cover with Vegetation (2)	Upwind (40)	7.7	1.00
Soil Cover with Vegetation (2)	Downwind (10)	5.2	0.49
Chemically Treated (3)	Upwind (40)	5.5	0.58
Chemically Treated (3)	Downwind (10)	6.4	0.80

Wind Direction:	S
Wind Speed:	16 km/hr (10 mph)
Hi-vol Height:	1.67 m (5.5 ft)
Temperature:	23.3°-26.6°C (74°-80°F)
Sampling Interval:	~2 hrs
Sampling Volume:	~102 m^3 (3,600 ft^3)
Soil Moisture:	1.7 wt %

Table 17. OPTICAL MICROSCOPE MEASUREMENT OF FIBER EMISSIONS FROM STATIC ASBESTOS CEMENT WASTE TEST PILES, SAMPLED ON NOVEMBER 17, 1975

Test Pile (No.)	Hi-vol Station (meters)	OM Concentration x 10^{-4}, fibers/m^3 Fiber Length >1.5 μm	>5 μm
Control (1)	Upwind (40)	4.8	0.60
Control (1)	Downwind (10)	5.8	0.67
Soil Cover with Vegetation (2)	Upwind (40)	(5.4)*	(0.80)*
Soil Cover with Vegetation (2)	Downwind (10)	6.4	0.95
Chemically Treated (3)	Upwind (40)	4.3	0.42
Chemically Treated (3)	Downwind (10)	5.8	0.61

Wind Direction:	S-SE
Wind Speed:	17.6 km/hr (11 mph)
Hi-vol Height:	1.67 m (5.5 ft)
Temperature:	21.1°C (70°F)
Sampling Interval:	~2 hrs
Sampling Volume:	~102 m^3 (3,600 ft^3)
Soil Moisture:	2.2 wt %

* Hi-vol blown over for undetermined length of time.

Table 18. OPTICAL MICROSCOPE MEASUREMENT OF FIBER EMISSIONS FROM STATIC ASBESTOS CEMENT WASTE TEST PILES, SAMPLED ON DECEMBER 11, 1975

Test Pile (No.)	Hi-vol Station (meters)	OM Concentration x 10^{-4}, fiber/m^3 Fiber Length >1.5 um	>5 um
Control (1)	Upwind (40)	7.7	0.56
Control (1)	Downwind (10)	7.8	0.90
Soil Cover with Vegetation (2)	Upwind (40)	6.0	0.20
Soil Cover with Vegetation (2)	Downwind (10)	8.0	0.74
Chemically Treated (3)	Upwind (40)	7.2	0.37
Chemically Treated (3)	Downwind (10)	6.0	0.75

Wind Direction:	S-SW
Wind Speed:	16-17.6 km/hr (10-11 mph)
Hi-vol Height:	1.67 m (5.5 ft)
Temperature:	17.8°-18.9°C (64°-66°F)
Sampling Interval:	~2 hrs
Sampling Volume:	~102 m^3 (3,600 ft^3)
Soil Moisture:	2.5 wt %

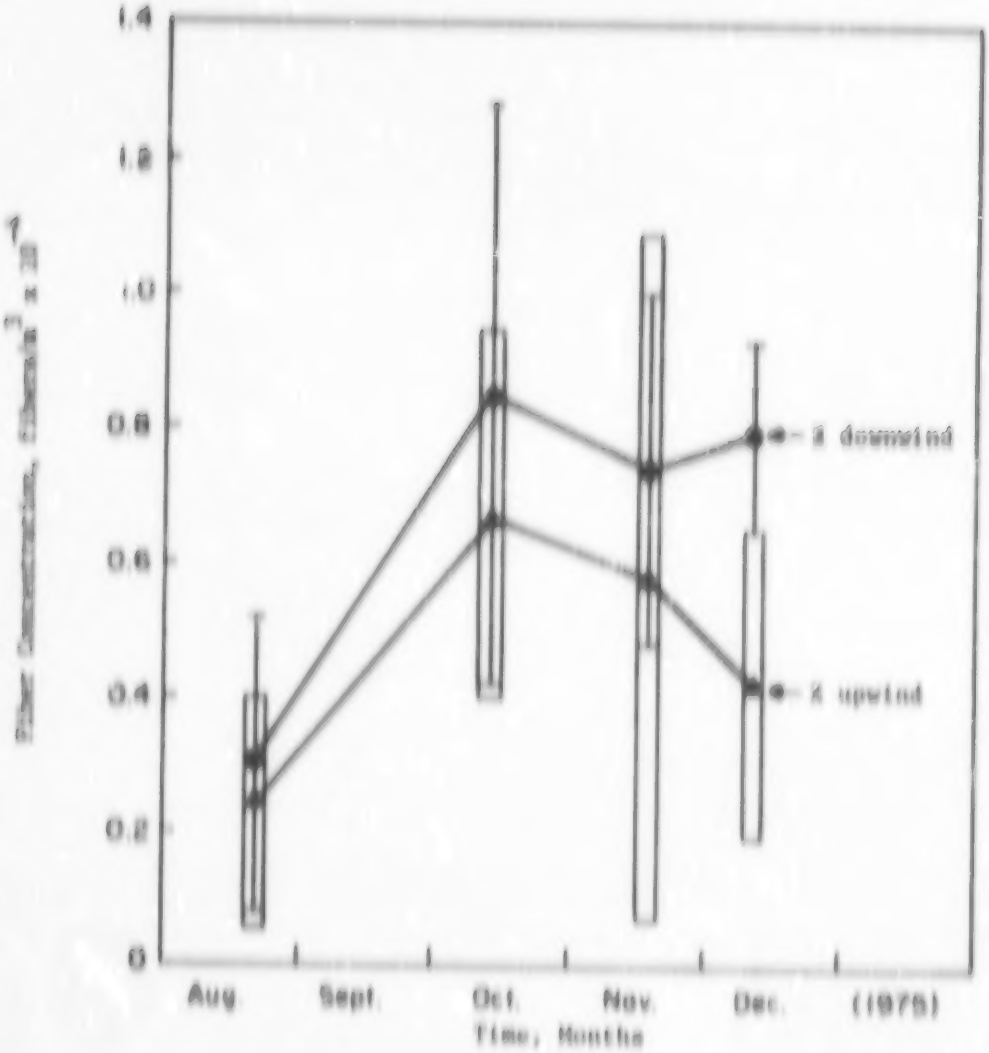


Figure 18. Fiber concentration vs. time for Hi-vol samples upwind and downwind from test piles. Concentrations and standard deviations shown from average PM counts of fibers >5 μm in length.

Table 19. t TEST OF AVERAGE UPWIND AND AVERAGE DOWNWIND FIBER CONCENTRATION MEASUREMENTS

Sampling Date:	08/21/75	10/13/75	11/17/75	12/11/75
Mean Fiber Conc. Upwind, $\bar{X}$ up, fibers/m^3 x 10^{-4}:	0.23	0.56	0.58	0.62
Mean Fiber Conc. Downwind, $\bar{X}$ down, fibers/m^3 x 10^{-4}:	0.30	0.85	0.74	0.79
Degrees of Freedom:	8	8	11	5
Standard Deviation, S:	0.44	0.59	0.55	0.44
$t_{measured}$	0.22	0.67	0.49	0.93
$t_{0.10}$	1.86	1.86	1.80	2.02

* When $t_{measured} \leq t_{0.10}$ the difference between $\bar{X}$ up and $\bar{X}$ down is considered to be not significant.

It was anticipated that the emissions from the test piles would be low and probably too low to be monitored since they had been treated to prevent emissions, however, some measureable emissions had been expected from the control pile. Emission tests were made at the test piles as a confirmatory measure, while the major effort was placed on establishing the chemical and vegetative cover to stabilize the dump and, thus, effectively eliminate emissions.

EMISSIONS FROM THE DUMP TRANSFER OPERATIONS

Emission measurements at the dump site were concerned with the activities of waste dumping, crushing of waste pile, and leveling of the material over the broken pipe waste. Three analytical techniques were used to analyze the membrane filter samples which were used to collect emitted particles via the high volume samplers. The analytical techniques were the electron microscope, optical microscope, and atomic absorption. The emission values obtained were used to back calculate the source term using the atmospheric dispersion estimation methods described by Turner.[11]

Fine baghouse waste produced a very strong visible emission which dissipated within the space of a few minutes, depending on the wind speed. High volume samplers required a fairly long time period in order to collect an adequate sample and thus, they were unsuitable for monitoring the dumping operation. For this purpose, a Royco light scattering particle counter, attached to a chart recorder, was used to obtain a record of the emission concentration as the cloud passed by the monitoring position.

Dumping operations were simulated with fines both slurried and bagged as emission control measures. The emission were monitored with the Royco Counter and the results are summarized in Table 20. Both methods appeared to offer excellent control over emissions. While the emissions from the controlled dumping were difficult to detect, the emissions released by the uncontrolled dumping drove the chart recorder pen off scale. A decrease in emissions of greater than 99 percent is estimated for this activity using either of the two control.

Comparison of Results for the Electron and Optical Microscope and Atomic Absorption

In all, 98 samples were analyzed from the 350 high volume samples taken. Analysis using the electron microscope is very time consuming and expensive and, in addition, the results are known to show considerable variation between replicates. It was thought that better data at lower asbestos concentrations could be obtained more rapidly by analyzing the filters by atomic absorption.

In Table 21, a comparison of the results obtained by electron and optical microscopes and atomic absorption is displayed. The filters were selected to demonstrate a range of activities at the dump which were of interest to the study.

Table 20. CONTROL OF EMISSIONS FROM FINES TRANSFER OPERATIONS AT THE DUMP; MEASUREMENTS MADE WITH ROYCO PARTICLE COUNTER

Load No.	Control Method	Weight of Waste Dumped: Wt %	Weight of Waste Dumped: Total, kg	Emissions Concentration, (Particles/m^3) x 10^{-11} >0.3 μm: Background: Quiet	Background: Gusts	Dumping (Above Background)
2	slurry - mixer	47	67	0.5	1.6	not detected
3	slurry - mixer	42	67	0.6	0.	not detected
4	dry - mixer	100	66	0.7	1.	>10 (off scale)
5	dry - mixer	100	66	0.7	0.	>10 (off scale)
6	slurry - mixer	42	100	0.7	3.	not detected, <0.2
7	slurry - mixer	30	70	2.5	steady	not detected, <0.2
9	slurry - mixer	35	83	1.5	steady	not detected, <0.2
10	bags - dumpster	100	450	1.2	steady	0.4 (?)
11	dry - dumpster	100	450	1.4	steady	>10 (off scale)

Table 21. COMPARISON OF ELECTRON MICROSCOPE, OPTICAL MICROSCOPE, AND ATOMIC ABSORPTION DATA FOR SAMPLES FROM FIVE LOCATIONS AT THE JOHNS-MANVILLE PLANT, DENISON, TEXAS

Station	Filter No.	Activity	Distance (m)	X_{EM} $f/m^3 \times 10^{-6}$	T_{EM} $f/m^3 \times 10^{-4}$	X_{AA} $ng/m^3 \times 10^{-3}$
3	7	Background	At Dump	1.2	5.2	3.02
24	68	Background	At Dump	2.1	9.3	6.3
24	30	Pipe Cracking	90	22.3	25.	31.8
24	72	Fines Leveling	35	18.9	30	46.3
28	75	Fines Leveling	130	10.2	29	18.3

It can be seen that there is reasonable agreement between the three techniques, especially with consideration for the known variability which exists in microscopic fiber counting methods. In general, the electron microscope concentrations are 10^1 to 10^2 greater than the optical microscope concentrations. These results are in agreement with samples taken previously at the dump site[11].

A further test was made to establish the feasibility of using the atomic absorption method, which is relatively rapid. 17 samples from a variety of sources and locations were analysed both by optical microscope and atomic absorption. The results are given in Table 22. The final column gives the ratio of the optical microscope count to the mass concentration measured by atomic absorption. The data is presented graphically in Figure 17. The close agreement of the data to the (OM:AA = 16:1 curve is readily seen. Based on this information, it was deemed justified to use atomic absorption as a measure of the asbestos emissions.

The Nature of the Emitted Fibers

Knowledge of the nature of the emitted fibers was necessary for several reasons. First, it was necessary to know whether the fibers observed on the filters were indeed asbestos. Second, an estimate of the average dimensions of the fibers was needed in order to derive the source functions for use in the dispersion model equation. Third, it was useful to have analytical evidence to establish that the ratio of asbestos to other particles, emitted from the waste, was in the same ratio as in the waste itself.

Identification of the fibers on the filter was performed by measuring the electron diffraction patterns and by obtaining the x-ray chemical spectra from individual fibers observed in the electron microscope. It can be seen from Table 23 that the large majority of the fibers exhibited the characteristics of chrysotile asbestos having a crystalline structure and magnesium and silica as their main elements. From the experience of examining very large numbers of standard samples of asbestos, it is estimated that very little error would be introduced by assuming all of the fibers to be asbestos.

Under the electron microscope, all of the fibers can be observed from the smallest to the largest. The dimensions, length and breadth, of all the fibers analysed in the above paragraph were noted. Frequency distributions by length and by breadth are given in Figures 18 and 19, respectively. It is seen that most fibers are less than 3 μm in length and less than 0.3 μm in diameter. Their mean aspect ratio as calculated from the ratios of individual fibers was found to be 10.2 (Table 24).

Asbestos containing samples from several different sources were examined for purposes of comparison. The samples included asbest cement waste fines, fines which had been sieved through a 200 mesh (<78 μm) screen, filter samples collected at the asbestos cement dump site, and relatively pure, commercial grade of chrysotile. (Plastobest 20, Johns-Manville Co.)

Table 22. ATOMIC ABSORPTION CONCENTRATION MEASUREMENTS AND OPTICAL MICROSCOPE FIBER COUNTS OF ASBESTOS EMISSIONS COLLECTED ON MILLIPORE TYPE AA MEMBRANE FILTERS; AIR SAMPLES COLLECTED ON PREMISES OF JOHNS-MANVILLE PIPE PLANT, DENISON, TEXAS

Activity Sampled[1]	Filter No.	Station No.[2]	Asbestos Concentration: OM Count R_{OM} fibers/m^3 x 10^{-4}	AA Analysis R_{AA} ng/m^3 x 10^{-3}	Ratio R_{OM}/R_{AA} fibers/ng
A	6	2	1.9	1.38	13.8
A	7	3	5.2	3.02	17.2
A	8	4	1.1	0.88	12.5
B	44	21	3.3	0.57	58
B	45	22	84.	56.	15.2
B	46	23	16.	5.8	24.
B	50	24	25.	31.8	7.9
C	64	22	6.4	4.5	14.
C	68	24	9.3	6.3	15.
D	72	24	30.	46.3	6.5
D	73	28	29.	18.3	16.
E	113	15	0.57	0.18	32.
E	114	9	1.00	0.61	16.
E	116	7	0.56	0.46	12.
E	117	8	1.27	0.48	27.
E	118	10	0.48	0.35	14.
E	119	12	0.80	0.53	15.

[1] A - area survey
B - crushing pipe at the dump
C - fugitive dust emissions at the dump
D - leveling fines at the dump
E - test piles

[2] For maps showing sampling station locations see:

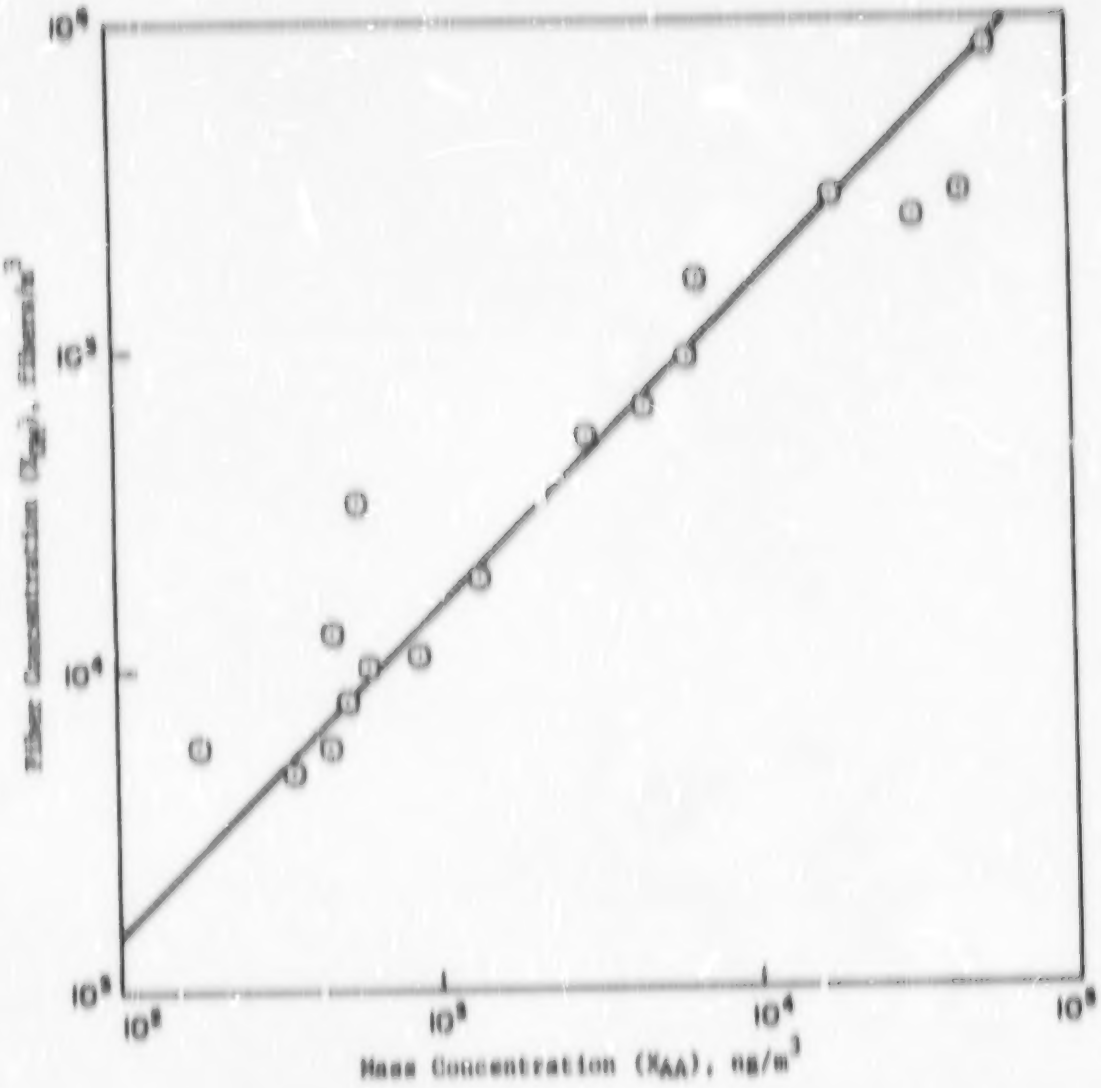


Figure 17. Comparison of fiber concentration (X_{OM}) and chrysotile mass concentration (X_{AA}) for field emission samples collected in vicinity of asbestos cement plant dump. A concentration of 15 fibers/ng shown by line.

Table 23. ANALYSIS OF SELECTED INDIVIDUAL FIBERS FOR CRYSTALLINITY AND ELEMENTAL COMPOSITION BY ELECTRON MICROSCOPY; SAMPLES COLLECTED ON 25-MIL MEMBRANE FILTERS AT ASBESTOS CEMENT WASTE DUMP

EM Grid No. (Filter No.)	Electron Diffraction		X-Ray Analysis			
	Crystalline	Non-crystalline	Mg-Si	Fe-Si	Mg-Fe-Si	Others
A-7(27)	35	8	7	1		
A-2(56), A-3(68)	18	1	3		1	1
B-1(58)	24	6	2		3	1
B-2(72)	31	5	2	1	2	
B-3(75)	23	2	4			1

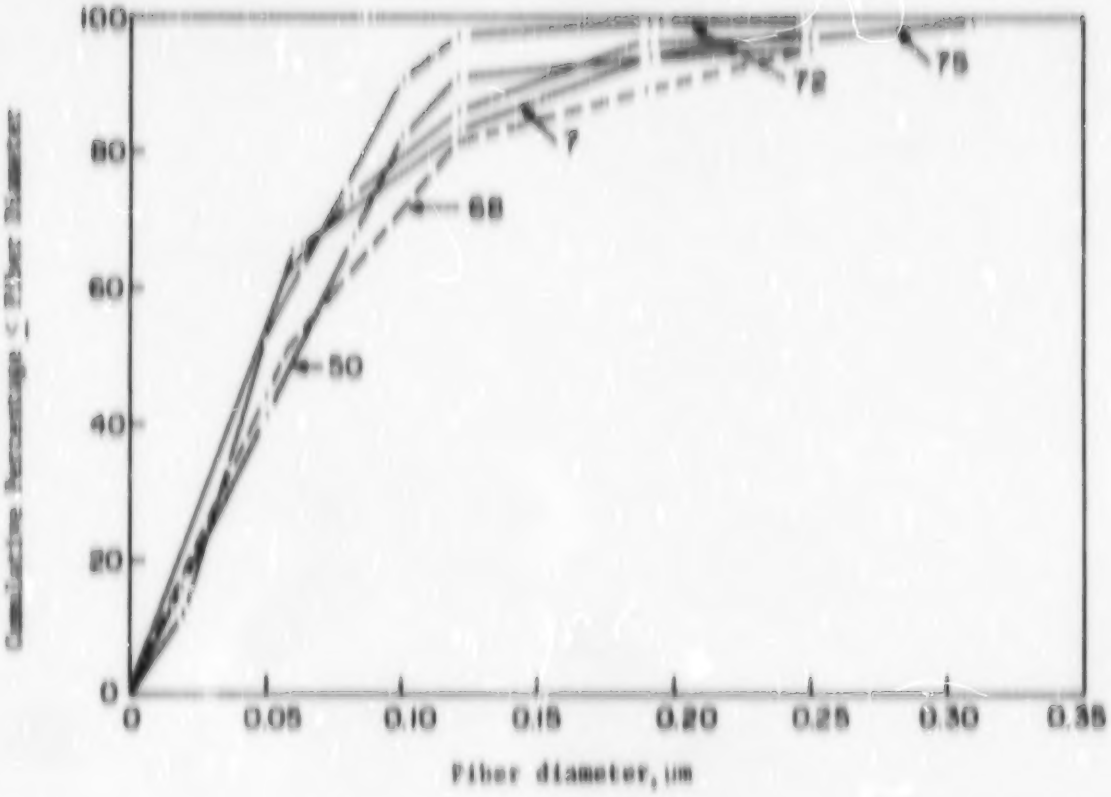


Figure 18. Cumulative distribution of fibers by diameter. Hi-vol samples collected on 0.8 µm pore size membrane filters at asbestos-cement waste dump. Measurements made on EM at 20,000X. Filter numbers indicated.

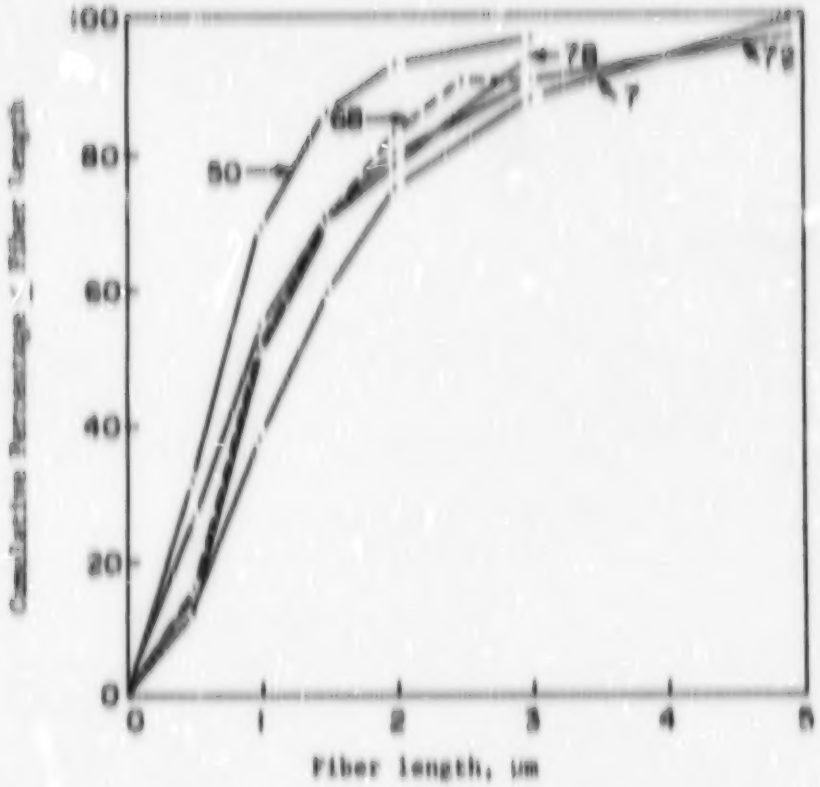


Figure 19. Cumulative distribution of fibers by length. Hi-vol samples collected on 0.8 µm pore size membrane filters at asbestos-cement waste dump. Measurements made on EM at 20,000X. Filter numbers indicated.

Table 24. COMPARISON OF FIBER ASPECT RATIOS FROM SEVERAL DUMP EMISSION SOURCES

Station No. (Filter No.)	Activity	Fiber Aspect Ratio: Mean Aspect Ratio	Fiber Aspect Ratio: Standard Deviation
3(7)	Dump Background	11.5	3.3
24(68)	Dump Background	8.3	2.0
24(50)	Crushing Pipe	8.0	2.1
24(73)	Leveling Fines	12.6	2.5
20(75)	Leveling Fines	10.6	2.1
	AVERAGE --	10.2	2.2

The results are shown in Table 25. Some variability in measured values resulting from different sample preparation methods have not been completely eliminated. However, common features related to the composition of the collected waste are clearly evident.

Comparison of the magnesium concentration of the whole fines from the dump and dump fines <200 mesh shows that the asbestos fibers in the waste segregate and tend to remain aggregated with the waste <200. On the other hand, the emissions which occur are due to those particulates which are in the fraction <200 mesh.

A comparison of the magnesium (Mg) to calcium (Ca) ratios is shown in Table 25. The Mg/Ca ratio for the high volume samples is intermediate between the Mg/Ca ratio for the whole fines and fines <200 mesh. This indicates that the proportion of asbestos emitted is more than would be expected from the proportion of fibers available in the emittable size range. Thus, asbestos fibers appear to be more readily emitted than other waste particles in the <200 mesh size range, and the overall proportion of asbestos emitted is close to its concentration in the bulk waste.

Emissions from Crushing and Leveling Activities

Emissions from the crushing and leveling activities were measured using an array of high volume samplers as described in Section 6 of this report. All downwind samplers were operated simultaneously for time periods ranging between 5 to 40 minutes. Downwind background samples were taken, when the bulldozer was not operating, for a period of one hour. Upwind background samples were taken for two hours. Full conditions for each of the experiments, numbered 11 through 19, are given in Appendix B-E.

The asbestos emission values calculated from atomic absorption analyses are given in Table 26 as asbestos concentrations at the point of collection. It can be seen that the emissions downwind exceed the background by as much as two orders of magnitude.

The source emission rate estimates shown at the bottom of Table 26 associated with each station were calculated first by assuming the wind to be blowing in a direction which placed each receptor in line with the source. Then a single wind direction was located to minimize differences between emission rate estimates calculated from all stations. The area source model was used to calculate the fugitive dust emission (downwind background) rates in Experiment 17. The bulldozer was involved in all other experiments and the finite line model was used to calculate source emission rates from them.

In Experiment 13, the wind direction was varying in such a fashion that no one direction could be justified to account for the emissions collected at all or even most of the stations. A point source model was used to get an initial emission rate estimate. Then a line source model was used to obtain an aggregate emission estimate from all the hi-vol stations. Close estimates of emission levels are difficult to make under

Table 25. COMPARISON OF MAGNESIUM CONCENTRATION AND MAGNESIUM TO CALCIUM RATIO FOR BULK WASTE FINES (WHOLE), WASTE FINES < 200 MESH (75 μm), AND FOR SAMPLES COLLECTED ON HI-VOL FILTERS AT THE DUMP

Sample Description	Sample Preparation Method (a)	Magnesium Concentration, Wt %	Concentration Ratio, Magnesium/Calcium
Dump Fines, whole	1	2.92	0.151
Dump Fines, whole	2	3.15	--
Dump Fines, whole	3	2.85	--
Dump Fines, whole	4	2.88	0.150
File 1 Fines, whole	2	3.30	0.183
File 1 Fines, whole	4	2.98	0.191
Dump Fines < 200 mesh	1	1.07	--
Dump Fines < 200 mesh	2	1.10	--
Dump Fines < 200 mesh	3	1.00	0.040
Dump Fines < 200 mesh	4	1.26	0.060
File 1 Fines < 200 mesh	4	1.13	0.078
Hi-vol Filter No. 54	4	--	0.088
Hi-vol Filter No. 55	4	--	0.081
Hi-vol Filter No. 56	4	--	0.118
Hi-vol Filter No. 57	4	--	0.074
Hi-vol Filter No. 58	4	--	0.090
Hi-vol Filter No. 78	4	--	0.108
AVERAGES:	whole fines	3.00	0.169
	fines < 200 mesh	1.11	0.059
	hi-vol sample		0.093

(a) 1. 5N HNO_3 digestion, 30 min.
2. HCl/HF total cations in soils, Method A 4-3, Perkin-Elmer.
3. Fusion, Method OC-4R, Perkin-Elmer (modified).
4. Conc. HNO_3 digestion, EPA-625-26-74-003, p. 82 (modified)

TABLE 26. ASBESTOS EMISSION CONCENTRATIONS AND EMISSION RATES FOR DUMP EMISSION SOURCES

Station No.[1]	Asbestos Emission Concentration, X_{Ab}, µg/m^3							
	Crushing Exp. 11	Crushing Exp. 12	Crushing Exp. 13	Crushing Exp. 14	Crushing Exp. 15	Background After Crushing Exp. 17	Leveling Old Fines Exp. 18	Leveling Fresh Fines Exp. 19
21 (upwind)	0.57	0.50	0.41	0.41	0.41	1.04	1.04	2.44
22 (downwind)	55.4	23.6	31.8	39.0	12.5	4.02	—	—
23 (downwind)	—	4.66	26.5	—	3.7	7.41	—	4.46
24 (downwind)	—	—	31.8	—	4.1	5.80	46.3	233.0
25 (downwind)	—	—	29.4	—	20.2	3.21	15.7	9.8
26 (downwind)	—	—	22.9	—	62.4	11.4	—	—
27 (downwind)	—	—	—	—	—	—	17.0	34.0
28 (downwind)	—	—	—	—	—	—	18.3	59.4
Wind:								
Direction	SE-SW	SE-SW	SE-SW	S	S-SW	S-SW	S-SW	SW
Speed, m/sec	1.3-6.6	1.3-6.6	1.3-6.6	1.3-6.6	1.3-6.6	3.9-6.6	5-8.7	4.5-5.3
Downwind Sampling Time, min	5	30	15	40	25	65	30	15
Source Emission Rate, µg/sec	40,600	14,500	69,000	26,000	32,000	36,000	48,000	200,000

[1]See map, Figure 11

our field conditions because they are highly dependent on the velocity and direction of a varying wind.

STABILITY OF THE CHEMICALLY TREATED PILE

Tests Applied to the Pile

In order to judge the effectiveness of the chemical treatment for stabilizing the test pile, a number of tests were conducted based on standard Soil Mechanics testing procedures. Where necessary, a comparison was made of the chemically treated pile against the control pile which was left untreated. The following tests were performed:

- Distribution of the stabilizer with depth
- Surface moisture analysis
- Wet sieve analysis
- Proctor penetrometer
- Shelby tube bulk density
- Settlement plate
- Channeling observation

Distribution of the Stabilizer

The stabilization of waste piles with a chemical binder is essentially a treatment of the top surface of the piles. Since the stabilizer was an organic compound, the binder concentration was estimated quite simply by measuring the carbon content of weighed samples of the pile. Measurements were made on material from the top, 0.65 cm below the top, and 1.25 cm below the top. The results as a function of time are given in Figure 20.

It can be seen from this figure that the carbon concentration at the top of the pile decreased steadily from a value of 12 percent carbon down to about 7 percent after seven months. Conversely, carbon concentration at the 0.65 cm and 1.25 cm levels increased from 1.6 percent up to 5 percent and 4 percent, respectively. It is reasonable to suppose that rainfall is responsible for the segregation of the stabilizer. It also appears that the stabilizer leaves the surface of the waste until a certain concentration is reached (about 5 to 6 percent from the present data) and then remains steady thereafter. The quantity is probably some function of the available surface and particle size.

Surface Moisture Content

Surface moisture measured in the top of the soil from the chemically treated pile and the control pile are compared to the rainfall data in

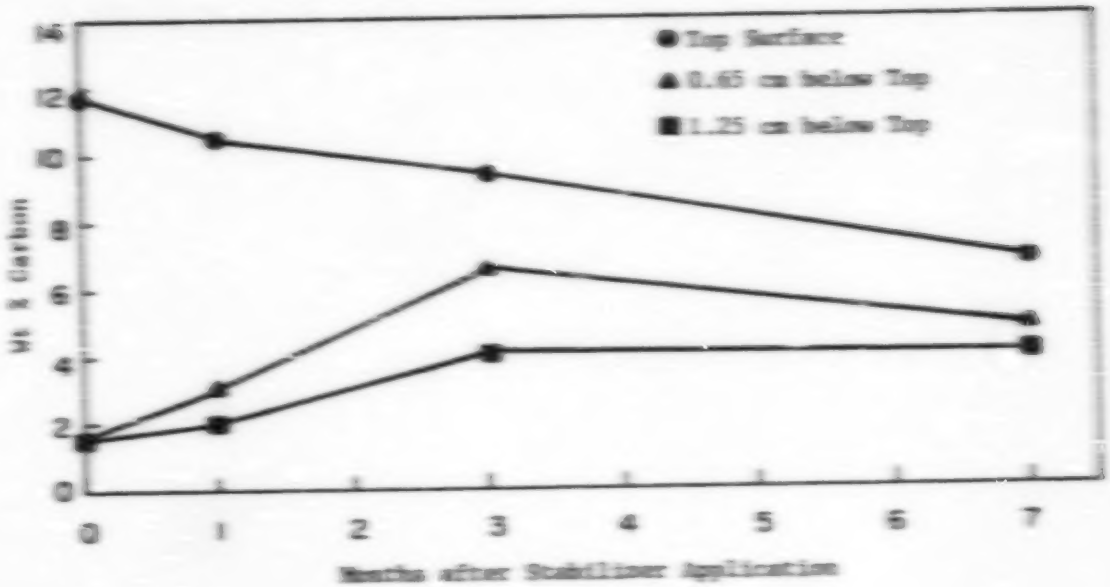


Figure 20. Concentration of the chemical stabilizer in the surface of Pile 3 shown as a function of time.

Figure 21. There appears to be no evidence to indicate that the moisture content is affected by the presence of the chemical stabilizer.

The soil moisture on the two piles was averaged and the average plotted in Figure 22 as a function of the length of time after each rain. A family of curves is apparent with curves associated with the greater amount of precipitation showing the greater moisture retention. The amount of moisture in the soil surface appears to directly related to the amount of precipitation and the number of days which have elapsed since the last rain.

Wet Sieve Analysis

Wet sieve analysis was utilized to measure the changes in particle size distribution of the surface material as a function of time. Standard sieves in range from 2 mm (10 mesh) to 37 μm (400 mesh) were used. The results have been tabulated in Table 27. The fine material from both the control pile and chemically treated pile has been lost from the surface. This loss could be due to downward percolation, agglomeration, it could be due to wind erosion. Most likely all events occur, but the low level of emissions collected on downwind high volume samples indicate that downward percolation and agglomeration, aided by rainfall, predominates.

The change appears to take place during the initial three months with very little further change occuring subsequently. The loss seems to coincide with an increase in penetration resistance as discussed below.

Penetration Resistance

The penetration resistance of the control pile and the chemically treated pile was measured using a Proctor Penetrometer fitted with penetration needles of 1.6 and 3.2 cm^2 cross section. Penetration resistance was measured at a depth of 5 cm. The results obtained as a function of time are given in Table 28.

Penetration resistance increased with time for both the piles. No distinction could be drawn between the control pile and chemically treated pile. Probably reasons for the increase are the percolation of the surface fines down to a layer where they interlock and bridge the voids; and there is probably some slow curing of the cement over a time period.

Bulk Density Measurement

Shelby tube samplers were utilized to obtain bulk density measurements. The Shelby tube is pressed into the pile until the depth of refusal (the point of strong resistance to penetration) is reached. The bulk density is then calculated at that point.

Table 27. WET SIEVE ANALYSIS OF THE CONTROL FILLE AND CHEMICALLY TREATED FILLE

CONTROL FILLE

Size, mm	Initial Sample Percent Passing Mean	Initial Sample Percent Passing Std. Deviation	Initial Sample Tested Later Percent Passing Mean	Initial Sample Tested Later Percent Passing Std. Deviation	After 3 Months Sample Percent Passing Mean	After 3 Months Sample Percent Passing Std. Deviation	After 6 Months Sample Percent Passing Mean	After 6 Months Sample Percent Passing Std. Deviation
2.0	74.4	1.0	74.72	0.62	71.5	6.9	72.47	6.32
0.3	38.4	5.0	21.09	1.97	20.2	5.5	20.93	8.24
0.15	18.0	2.5	9.37	1.93	10.3	3.9	13.84	6.31
0.105	14.6	2.8	6.41	2.14	7.6	3.3	10.72	5.02
0.074	12.4	2.9	5.06	1.78	6.1	3.2	8.89	4.14
0.044	9.8	4.1	2.58	1.21	3.6	2.6	6.45	3.08
0.037	8.5	3.2	2.44	1.00	3.3	2.8	5.83	2.50

CHEMICALLY TREATED FILLE

Size, mm	Initial Sample Percent Passing Mean	Initial Sample Percent Passing Std. Deviation	Initial Sample Tested Later Percent Passing Mean	Initial Sample Tested Later Percent Passing Std. Deviation	After 3 Months Sample Percent Passing Mean	After 3 Months Sample Percent Passing Std. Deviation	After 6 Months Sample Percent Passing Mean	After 6 Months Sample Percent Passing Std. Deviation
2.0	86.58	5.5	88.0	3.7	73.2	4.4	80.76	2.80
0.3	41.7	16.3	42.6	17.3	21.8	3.5	27.34	4.05
0.15	28.9	15.8	30.2	16.0	13.2	4.1	15.30	2.65
0.105	24.1	14.7	24.9	13.9	10.3	3.8	11.88	2.26
0.074	19.3	12.6	20.9	12.0	8.7	3.2	9.70	1.92
0.044	12.8	8.3	12.8	7.5	5.9	2.2	6.54	2.02
0.037	11.4	6.6	12.3	7.8	5.6	1.9	7.17	1.58

Table 38. PENETRATION RESISTANCE (Newtons)[a]

Position (Time)	Control Pile		Chemically Treated Pile	
	1.6 cm^2	3.2 cm^2	1.6 cm^2	3.2 cm^2
1 (Initial)	196	320	205	311
1 (3 Months)	343**	329**	418**	267**
1 (6 Months)	245	311	409	222
2 (Initial)	267	436	234	329
2 (3 Months)	400**	520**	494**	440**
2 (6 Months)	431	383	449	538
3 (Initial)	236	409	169	231
3 (3 Months)	400**	334**	525	302**
3 (6 Months)	369	498**	365	476**
Averages:				
Initial	231	387	209	289
3 Months	383**	396**	480**	338**
6 Months	347	396**	409**	414**

[a]Averages of three or more measurements at each location.

**Virtually no penetration for one or more measurements.

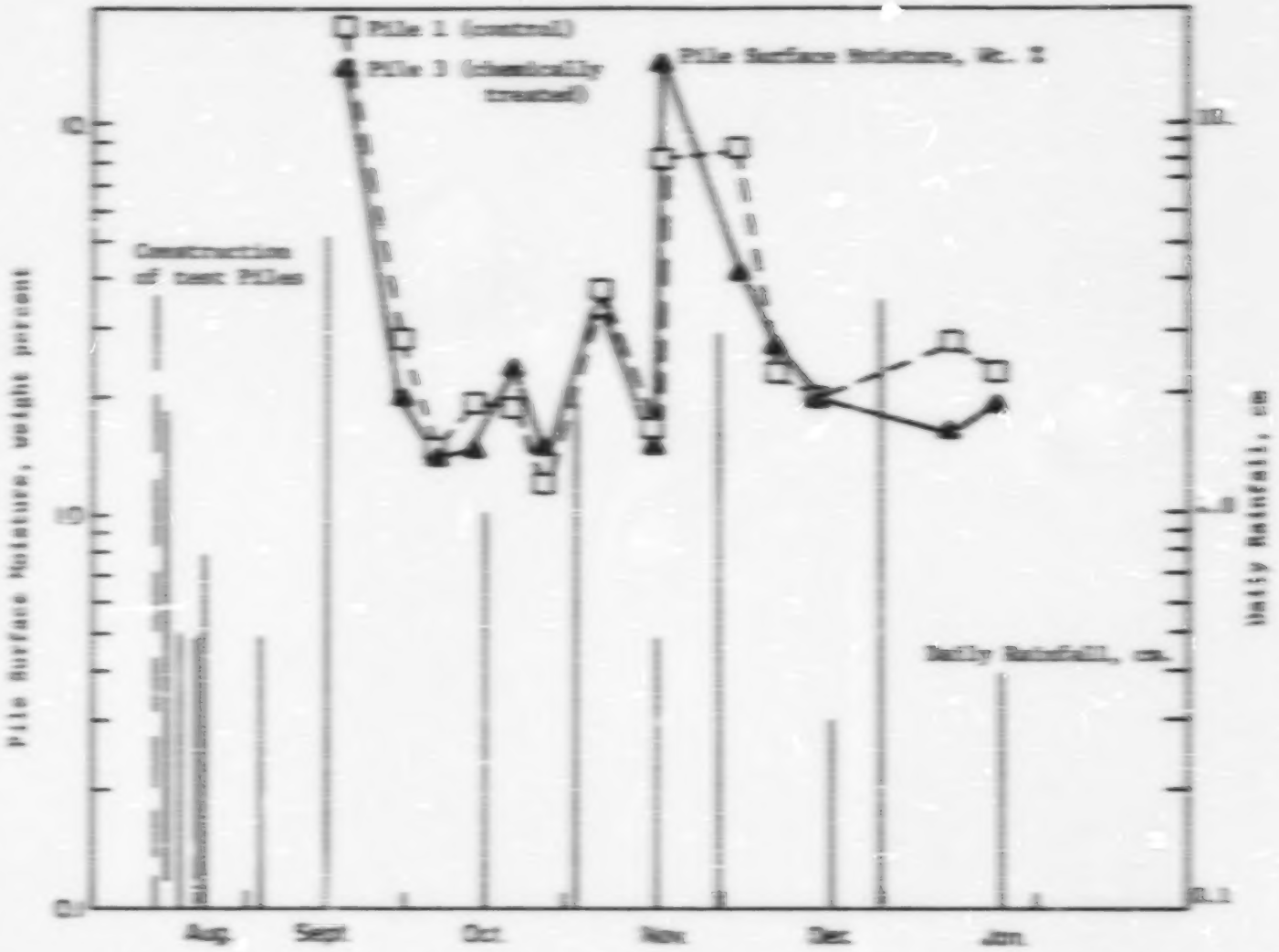


Figure 21. Comparison of daily rainfall and surface moisture on test piles 1 and 3 over six months period.

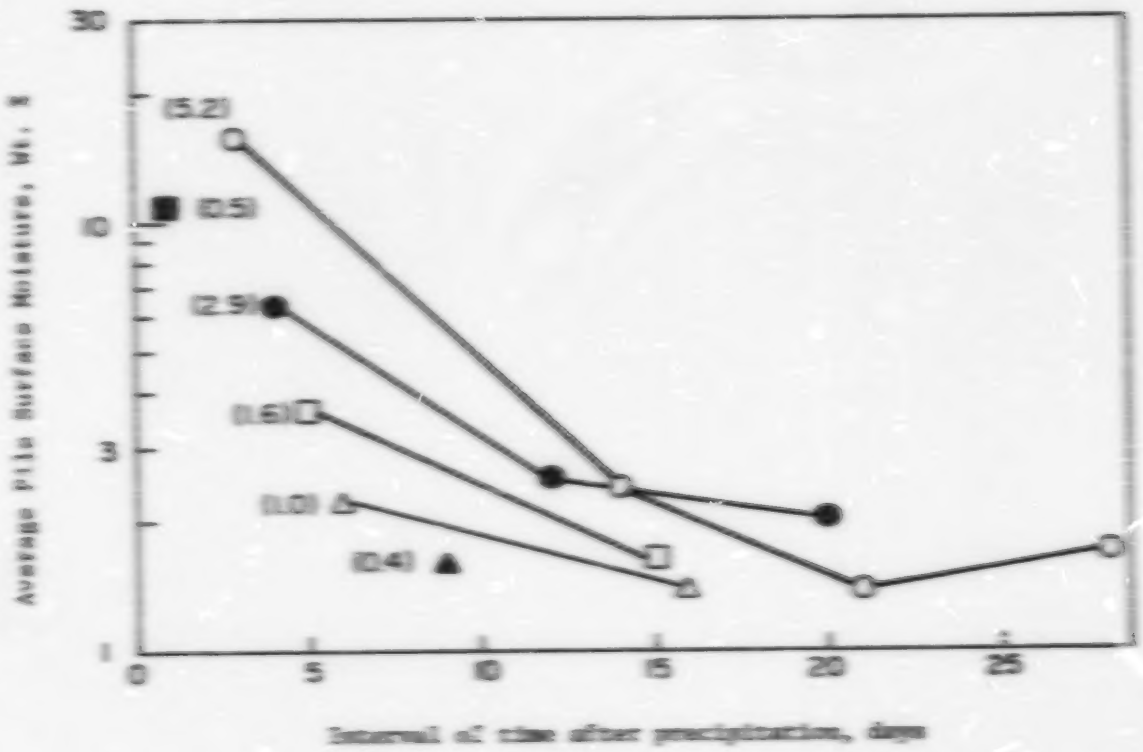


Figure 22. Comparison of average surface moisture on piles 1 and 3 at different intervals of time after precipitation. Amount of precipitation (in) is shown in parenthesis.

The results obtained are given in Table 29; as anticipated, considerable scatter in the results is evident. It was hoped that the stabilized pile might show a more consistent set of values. No such inference can be made and, hence, the results are inconclusive.

Settlement Plate Measurements

The settling plate waste levels were measured to get an indirect estimate of the wind erosion surface loss from the test piles. These estimates were based on the differences between the initial pile surface mass and the losses with time by consolidation. The consolidation of the waste was calculated from the bulk density measurements, and the volume from the settling plate change in waste level.

The changes in settling plate waste levels over the life of the piles are shown in Table 30. They show that the emissions collected on the high volume samplers result from small mass changes which are not easily measurable from the settling plate data.

Observation of Channeling

Observation of the surface of the piles gave no evidence that channeling, as a result of rain action, was disturbing either the control pile or the stabilized pile. Apparently, good drainage is experienced through the pile in both cases. This is a positive result since it was found that the stabilizer might have a surface sealing effect. This would have led to surface drainage channels and, eventually, a break-up of the pile.

Summary of Chemical Treated Pile Results

In general, it was observed that the chemically treated pile was stabilized very effectively. The stabilizer adhered well to the waste particles, reaching a steady level which was not removed after seven months of weathering by heat and rain. In the surface moisture tests, it was found that the presence of the stabilizer did not affect the water retention in the top surface. It was feared that the stabilizer coating might "waterproof" the treated pile and, thus, reduce the water retention. The ability to retain water is important since moisture is very efficient in reducing surface emission. Wet sieve analysis of the surface indicated that fine material was lost from the surface either by percolation or by emissions from the surface with no discernable difference between the control piles and the treated pile.

The Soil Engineering tests, that is, penetration, bulk density, settlement plate, and channeling observation, all indicated that the control pile and the chemically treated pile were well stabilized. The stability of the control pile is probably due to the waste material having a residual of uncured Portland cement. As the cement slowly completes its curing, then the pile will attain a natural degree of stabilization. The stabilization achieved from the cement curing actually masked the effect

Table 39. SHELBY TUBE BULK DENSITY (gm/cm^3)

File Number	Initial	3 Months	6 Months
1 (control pile)	1.30	0.886	0.626
	1.05	0.803	1.183
			0.812
Average	1.18	0.84	0.87
3 (chemically stabilized pile)	0.705	0.775	0.742
		0.747	0.768
			1.337
Average	0.70	0.76	0.95

Table 30. SETTLING PLATE MEASUREMENTS

File Number	Settling Plate Number	Settling Plate Waste Level,* $(L_0 - L_t)$, mm		
		Initial	3 Months	6 Months
3 (chemical treatment)	1	0	0	- 3.2
	2	0	+ 3.2	+ 3.2
	3	0	0	+ 3.2
	Average	0	+ 1.1	+ 1.1
1 (control)	1	0	- 6.4	- 9.5
	2	0	+ 6.4	- 3.2
	3	0	0	0
	Average	0	0	- 4.2

*Waste level values > 0 show increased waste volume, values < 0 show decreased waste volume.

of small quantities of stabilizer added to the treated pile. The purpose of the added stabilizer was to achieve only a stable crust or outer layer.

Emission testing from the piles would give the most positive information on whether the stabilized top surface was at a lower emission rate. Unfortunately, as reported earlier, the background interfered with the sensitivity of the emission level testing.

STABILITY OF SOIL-VEGETATIVE COVER

General

The object of the vegetated soil cover was to provide a layer of soil which would effectively prohibit the emission of asbestos from the waste pile, and to stabilize the soil from erosional effects by growing a vegetative cover on the soil. A 70 percent foliage cover was recommended for soil stabilization purposes by the consultant agronomist to this program, Dr. W.A. Berg.

After reviewing the sandy loam to be used for covering the asbestos waste, Dr. Berg recommended that a 30 cm soil cover be used. This is in contrast to the 15 cm cover proposed by the Environmental Protection Agency in the latest amendments to the national emission standards for asbestos. The depth of the soil cover should be a function of the water retention capability of the soil. Thus, for example, a deeper bed of an open structured sandy loam is required in contrast to a shallower bed of soil with a high clay content.

A number of tests were performed to establish the vegetative cover and to establish effectiveness of this treatment. The tests applied were:

- Mineral composition
- Relation between rain and vegetative cover
- pH of the bed
- Conductivity of the bed
- Observation of vegetation
- Observation of channeling

Mineral Composition

In order to establish a vegetative cover, it is essential that the soil contain the necessary minerals to sustain plant growth. An analysis of the soil and the waste material was made and the results are given in Table II. The soil was found to be extremely deficient in plant-available phosphorus and low to moderate in potassium. The nitrate test meant little

Table 11. SOIL ANALYSIS OF TEST SAMPLES

Test Material	pH	Mineral Concentration, ppm			Conductivity (Soluble Salts), mmhos
		NO_3-N	P	K	
Sandy loam, pile soil cover	8.1	10	1	53	0.6
Fresh asbestos cement waste fines	10.2	24	105	1,100	1.4
Buried asbestos cement waste fines	11.1	19	57	630	0.8

in terms of a disturbed site such as this; past experience indicated the soil would be extremely nitrogen deficient.

The soil required fertilization with nitrogen, phosphorus, and potassium. Fertilization with adequate rates of phosphorus and potassium would give the necessary long-term effects. Nitrogen is subject to leaching and nitrogen fertilization effects would usually be limited to the season of application. Thus, nitrogen fertilizer was applied to obtain a good initial ground cover of herbaceous species and the long-term nitrogen would, hopefully, be supplied by the the legume, black medic, which was in the seeding mix.

Relation Between Rain and Vegetative Cover

In Figure 33 are shown the percentages of vegetation coverage and the cumulative rainfall over the six month period from August 1975 through January 1976. Vegetation coverage on the pile during the first six weeks was not related to rainfall since the pile was sprinkled at the rate of 5 cm of water per week during that period. The vegetation achieved a coverage greater than 70 percent during the first two months. When the sprinkling was terminated, the plot was able to maintain a greater than 70 percent coverage for the rest of the six month period. The rainfall itself was fairly constant over the whole six months, giving an average of 0.8 cm of rain per week.

In many parts of the country, the rainfall is very limited and the desired coverage might not be easily maintained. As a rough rule, a minimum of 38 cm (15 in) annual rainfall would be required for a 70 percent coverage. However, there are many exceptions; for example, effectiveness of rainfall in the upper midwest is much greater than in the southwest. A 30 cm annual rainfall in North Dakota might require a 51 cm rainfall in Southern Arizona for comparable coverage.

Soil pH

Soil samples were collected for pH measurements four months after the pile had been constructed. Samples were collected from six locations over the pile using a Shelby tube. The pH measurements are shown in Table 32. The values obtained may be compared to the original value of the soil, pH = 8.1

The pH values measured on the soil varied from 7.12 on the north end of the pile to 8.57 on a core sample from the south end of the pile. The average pH is 8.12 for these cover soil measurements. The pH level variability across the pile suggests that some mixing-in of the waste during pile preparation had occurred. The mixing might be largely avoided if the waste is wetted down just before the cover soil is added on the pile. This would prevent movement of the waste fines up into the cover as air is rapidly expelled from the loose waste fines during cover soil addition. A high pH is not supportive of plant growth and efforts should be taken to minimize contamination of the cover soil by the waste.

Table 32. pH MEASUREMENTS OF SANDY LOAM SOIL COVER ON PILE AFTER FOUR MONTHS

Core Sample Depth	pH Measured on Core Samples from Pile 2					
	1	2	3	4	5	6
Top of Soil	7.12	8.18	8.10	8.24	8.33	8.40
Middle of Soil	7.80	7.86	7.87	8.30	--	8.57
Bottom of Soil	--	8.23	8.03	8.16	--	8.57
Top of Asbestos	--	11.55	--	12.02	--	11.86

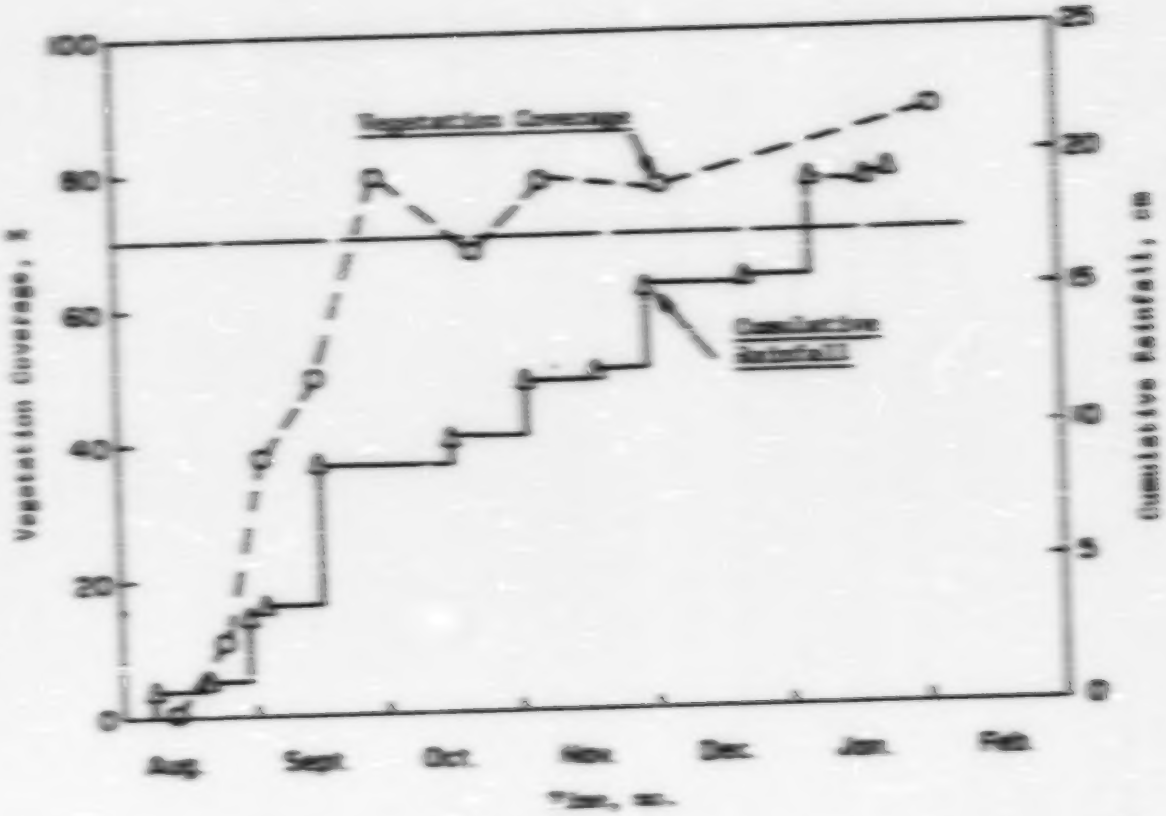


Figure 23. Comparison of vegetation coverage on Pile 2 and rainfall over six month period.

Electrical Conductivity

Soluble salts in the soil increase the osmotic potential in the soil solution and thus, can delay or inhibit germination and reduce the plant available water. The amount of soluble salts in the cover soil was determined by measuring the conductivity of selected soil samples. Measurements were made on saturation extracts and compared to the accepted effect of conductivity on plant growth which is as follows:

Electrical Conductivity, mmoho	Effect on Plants
0-2	Salinity effects usually negligible
2-4	Affects yield of very salt sensitive plants
4-8	Affects of salt sensitive plants
8-16	Can be tolerated by only a few special crops
>16	Unsatisfactory yield from most species

The data from the soil samples (Figure 24) indicated very little salt movement upward into the cover soil from the asbestos cement waste below. Some of the soil samples show high conductivity values compared to that of a fresh sandy loam sample from the original cover soil; however, these values may reflect the rather heavy fertilization of the cover soil. The soluble salt concent in one of the asbestos cement waste samples is relatively low. This may due to rapid leaching on this part of the waste pile.

A comparison is made in Figure 24 between the electrical conductivity and the pH measured for each soil sample collected. It can be seen that the greatest pH and electrical conductivity are associated with the waste itself, while most of the cover soil and pH value are clustered around a pH of 8 and an electrical conductivity value of 1 mmoho.

Observations of Vegetative Cover

After seven months, the level of ground cover was found to be more than adequate to control water and wind erosion. The intensive treatment resulted in the production of a 95 percent ground cover of vegetation in spite of an unusually low level of precipitation during the intervening months. The test period included much of the expected "rainy season" of the year. However, the test site received only 20 cm of precipitation during the end of January. The average annual rate of rainfall for the area over the last ten years was 106.4 cm per year.

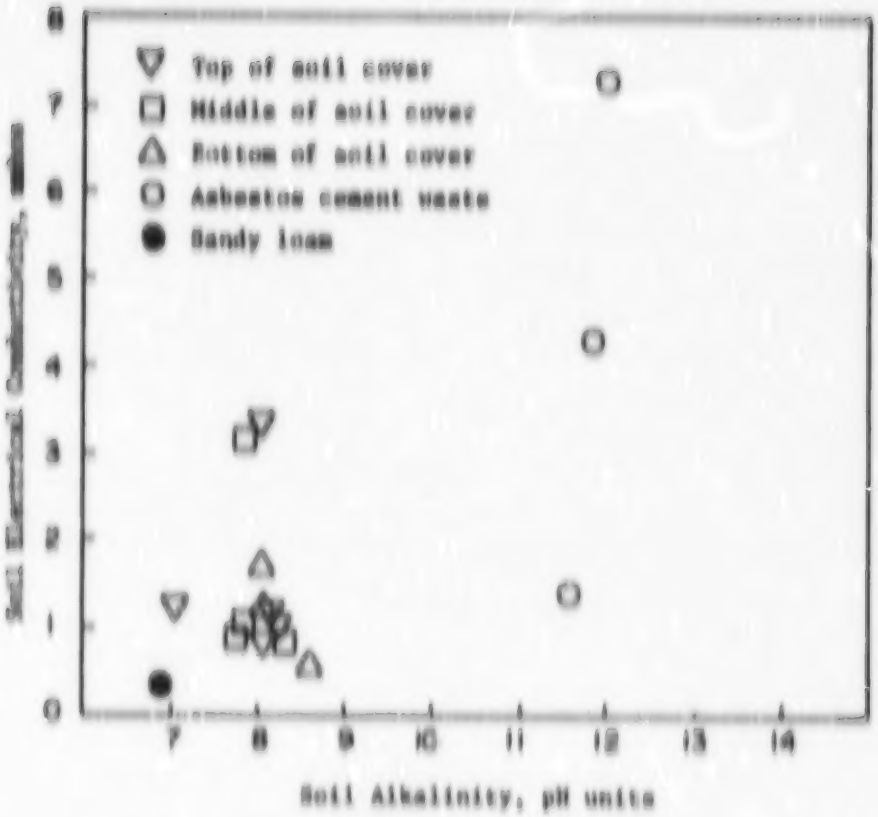


Figure 34. Comparison of soil electrical conductivity with soil pH on Pile 2. Values for sandy loam are included for reference.

At the end of seven months, the plant growing on the top of the pile were light green in color. This indicated a nitrogen deficiency which was probably caused by leaching in the vicinity of the sprinkler. No fertility problems were evident on the vegetation growth on the sides of the pile.

A hole dug on the top of the pile revealed roots in the soil extending down to the fine asbestos-cement waste. The roots did not grow into the waste but stopped at the soil-waste interface. Root penetration into the asbestos-cement waste is not expected until a considerable drop in pH takes place. The pH will eventually drop as the lime in the cement is converted to carbonates.

Cereal oats and weeping lovegrass dominated the vegetation on the pile. The ground on the near-level top was covered with (about 95 percent) cereal oats from seed introduced in the straw mulch. A fair to good stand of weeping lovegrass was present among and under the oats; thus, weeping lovegrass would provide vegetative cover once the oats matured and decayed. A few black medic seedlings were present on the top. Only a very few tall fescue seedlings were present on the entire pile. Tall fescue was expected to be the major species growing on the pile. Possibly this species did not establish because it is a cool-season species and the pile was seeded in the warmest part of the summer.

The domestic oats which produced much of the ground cover was introduced in the straw mulch. If possible, it is preferable to use hay of the species one desires to establish as the mulch, thus avoiding introduction of undesired seed. The oats are fast-growing, annual plants which interfere with the establishment of the perennials from the revegetation seed mix. Succession would be eventually transferred to the encroaching native species.

Weeping lovegrass was much more abundant on the sides of the pile than on top. Weeping lovegrass makes much of its growth when the weather is warm -- thus, most of the plant material present was dry material from last season. Black medic was also more abundant on the sides of the pile. Black medic was the major species on the slightly disturbed soil areas immediately adjacent to the plot. Black medic had substantial green growth and inspection of the roots revealed numerous small nitrogen-fixing nodules.

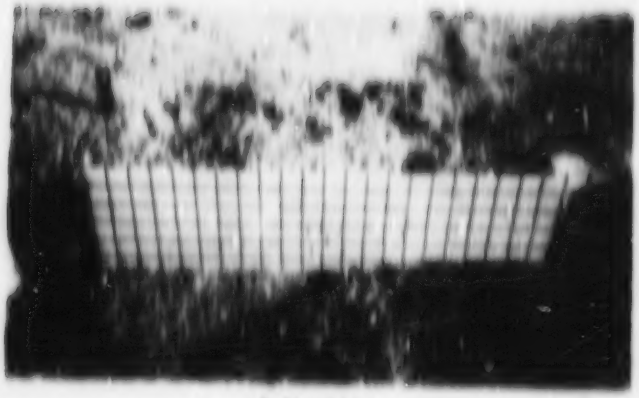
Observation of Channeling

Channeling was not observed to be a serious factor in either the control pile or the soil/vegetatie test pile. The test rig used to estimate the channeling is shown in Figures 25 and 26. It is apparent that movement of the piles on a gross scale was not a problem during the period that the piles were under test.

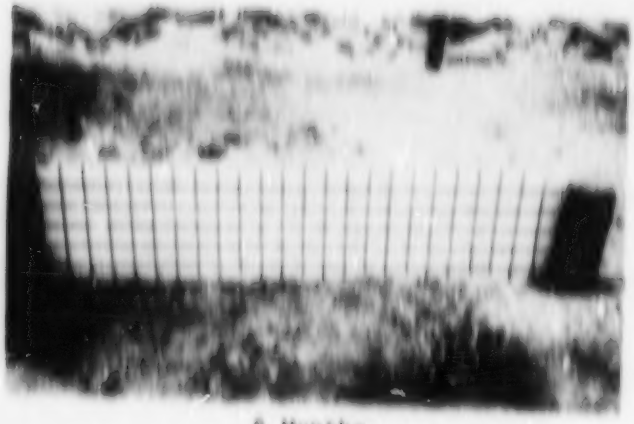
Summary of the Soil-Vegetated Cover Tests

It was demonstrated that given a sufficient depth of soil cover, a vegetative cover could be used to stabilize asbestos waste piles. Fertilizers are available to supplement those lacking in the soil to be used for the cover and soil tests must be made to establish the nutrient levels in the soil.

Initial

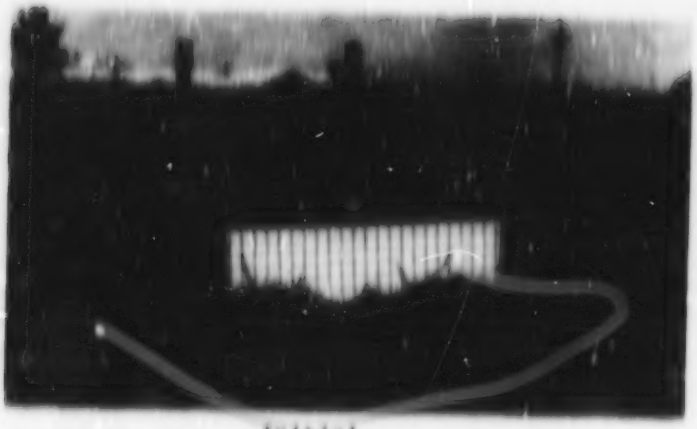


3 Months



6 Months

Figure 25. Typical comparison of channeling on a non-vegetated pile (control).



Initial

3 Months

6 Months

Figure 26. Typical comparison of channeling on vegetated pile (#2).

The high pH and electrical conductivity associated with asbestos waste piles can be tolerated. In order that these factors do not interfere with plant growth, it is necessary to have a sufficiently deep soil cover and to avoid mixing of the soil with the waste fines.

The vegetation planted on the waste pile resulted in a very adequate vegetative cover. A minimum of a 70 percent cover was considered as adequate to stabilize the pile against erosion. In fact, a 95 percent cover was developed.

The pile was found to have a very high stability in terms of lack of gross surface movement, or channeling.

SECTION 8

APPENDICES

A -- COST ESTIMATION OF CONTROL TECHNIQUES FOR THE DUMPING OPERATION

Fine Control -- Assumptions

- Fine are collected from three baghouses daily. Each baghouse produces 0.3 metric tons/day or 300 kilograms/day/baghouse. Bulk specific density of 0.4 gms/cc.

- The emissions from the dumping of the asbestos fines was previously estimated at 4.5 kg per dumping operation (once per day) averaged over the entire year. This results in an emission rate of

  34×10^{9} nanograms/hr

or

  34×10^{12} asbestos fibers/hr

- Waste asbestos from the baghouses is transported to the active pile by 2.5 cu meter load-lugger. No asbestosemissions occur in the plant from the loading of the load-lugger. The load-lugger makes two trips per day.

- Particle size of the emitted asbestos assumed to be 1 um diameter and 3 um long.

Fine Control -- Water Spray at Dump Site Method #1

Based on the attached Figure, the particle collection efficiency for particles having a diameter less than 4 um is extremely low (20 percent). Because we have assumed that the average particle size emitted is only 1 um diameter and 3 um long, water sprays at the dump site will be ineffective.

Any form of water sprays must rely on the impingement by the spray droplets. For maximum impingement capture, the optimum droplet particle size is about 100 microns.[illegible] Hanf and MacDonald[illegible] reported that the collection efficiency for particles less than 5 microns was less than 50 percent. Figure 27[illegible] indicates that the collection efficiency for particles less than 5 microns is very low indeed, with no apparent removal achieved for particles less than 3 microns. Because the asbestos particles average only 1 micron

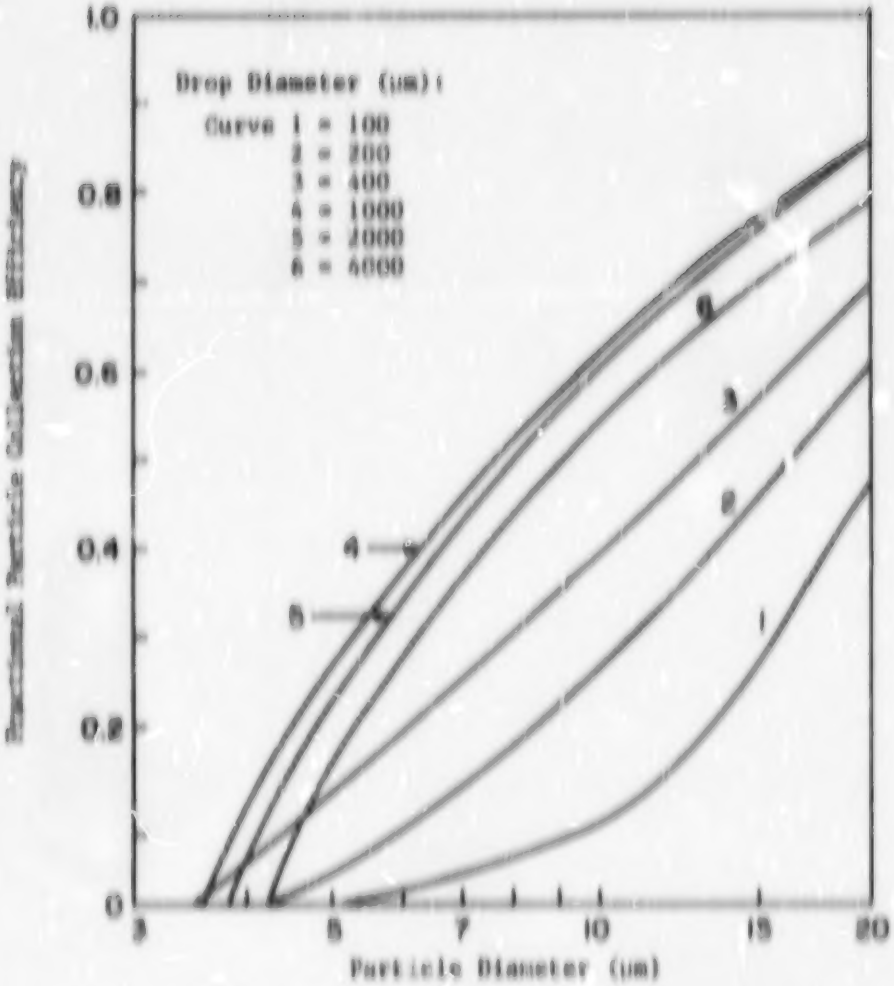


Figure 27. Collection of particles by free falling water drops.

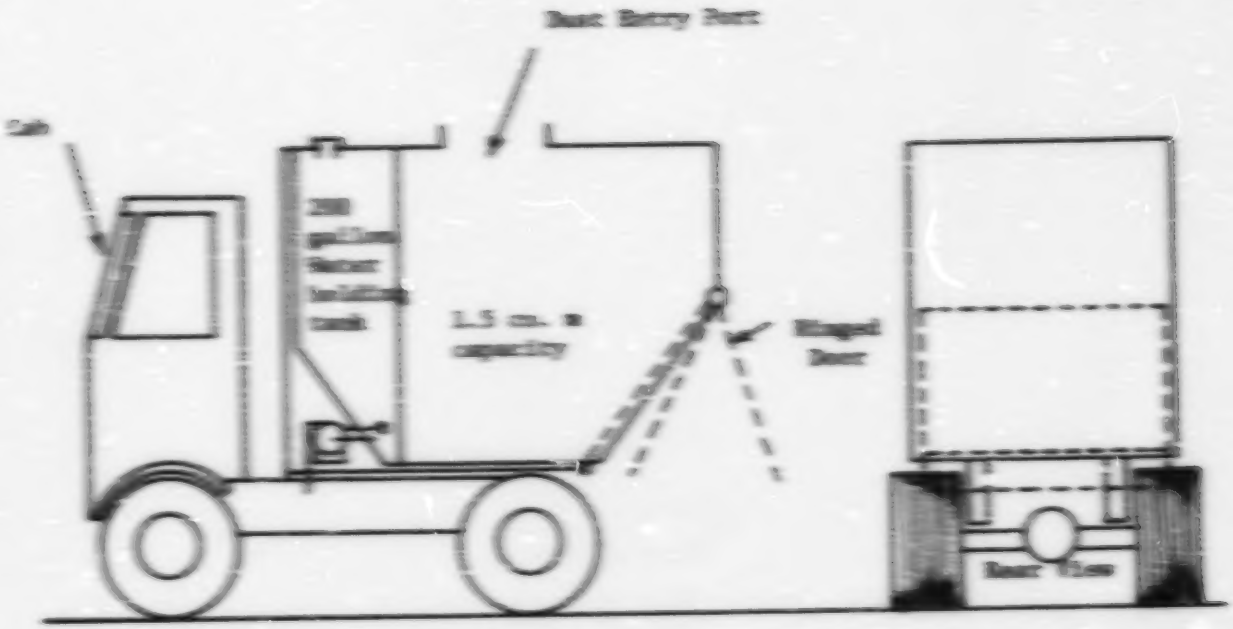


Figure 20. Modified loadlogger with spraying system.

diameter and only microns in length, a water spray system will be very ineffective, we will assume an efficiency of 10 percent removal.

Annual Cost

The load-lugger will be modified into a 2-compartment vehicle. An electric motor (1.5 hp) and a 60 gpm pump (at 40 psi) will be mounted on the load-lugger. Flat spray nozzles (PVC) and PVC piping will be mounted around the hinged door area. A schematic is shown on the following page. The spray system will operate for approximately 3 minutes. A level control will shut the pump down. Flat spray type nozzles (i.e., Delvar Mfg. Nozzle Type WF, ¼", 2 gpm at 40 psi) will be located every 6" around the rear of the vehicle. The following capital cost estimate was prepared.

2-compartment modifications	$600
Purchase electric motor and mount	600
Purchase 60 gpm, psi pump	700
PVC nozzles and pipe	200
Installation of system	1600
	$3700

Because of the rough environment, we will assume an equipment life of 5 years and a cost of capital at 10 percent per year. The following annual cost was estimated.

Annualized capital cost	$1000
Additional operating labor (30 min/day at $8/hr)	1200
Maintenance (time and material)	600
	$2800

(Note increased energy cost with this method is negligible)

Fines Control -- Surface Addition to Water Spray Method #2)

Through the addition of a surfactant or wetting agent, the surface tension of water can be lowered by a factor of 2 to 3.[illegible] The addition of the wetting agent gives the water the ability to cover the surfaces and to agglomerate the dust particles. Although these compounds increase the ability of water to prevent particles from becoming airborne[illegible] there is considerable doubt that the wetting agent significantly improves the collection efficiency of particles already airborne.[illegible]

Based on the 10 percent collection efficiency with just water, we will assume the collection efficiency improves to 20 percent, with the use

the surfactant. The only additional cost over the water spray system will be the purchase chemical cost. Typically 1 gallon of surfactant per 1000 gallons is utilized[11], and will typically cost $8 per gallon or installation cost of $3000 (includes additional $300 handling the chemical).

Annualized Capital Cost	$1000
Operating labor	1200
Maintenance	600
Chemical	300
	$3400/yr

Fine Control Method #3 -- Agglomeration with Water Only

Ferro-Tech, Incorporated, has successfully pelletized asbestos dust fines[16,17]. Ferro-Tech reported that from 15 to 40 percent moisture would result in a bulk density of 40 to 60 lb/ft^3 and crushing strengths of 3 to 6 pounds wet and 5 to 10 pounds when dried.

We will assume that one centrally located pelletizing disc unit will be utilized. Unit will be sized for 22 metric tons per day, or approximately 1 hour is required to process the daily load.

This system should be very effective in reducing the dumping emissions, we estimate a 90 percent reduction in the dumping operation alone. Also, because the the asbestos is pelletized, there will be some reduction from the active pile emission. However, with just the water as the binder, the life of the pellets will be short, perhaps 2-4 weeks before they revert back to fines. Thus a reduction of perhaps 5 percent in the emissions from the active pile will be achieved.

Cost

Based on data provided by Ferro-Tech, we estimated the installed cost for 2100 lb/hr disc pelletizer with all auxiliary equipment at $25,000. The life of the equipment is estimated at 10 years.

Annualized capital Cost (10% cost of capital)	$4100
Additional operating labor (2 hrs/day at $8/hr)	4000
Maintenance (time and material) (3% of capital investment)	800
Electrical	100
	$10,000

Fines Control Method #4 -- Agglomeration with a Chemical Binder

The use of a binder should improve the life of the pellets once the fines are dumped on the active pile. Ferro-Tech reports up to a 10-fold increase in crushing strength with the use of a binder. We will assume that the dumping emissions are reduced by 90 percent, and active pile emissions by 25 percent. The cost of the binder and the quantity used varies a great deal from 0.005 percent to 2 percent of the feed at prices from $0.25 to $4 per pound. The average annual price for the binder is ~$3000 or the total annual cost is $13,000.

Fine Control Method #5 -- Water Slurry

By slurrying the fines prior to dumping them on the active pile, there should be a significant reduction of asbestos emission during the dumping operation. Slurrying in the present vehicle (the load-lugger) is probably not feasible because there is no mixing provided and the tail gate would probably not support and hold the water in. The fines could be slurried at each baghouse prior to loading the truck, but this would require a separate blending operation at each site. Instead, a cement type truck would be more practical. The vehicle could fill half way up with water prior to collecting the fines, mix the fines and water thoroughly and then dump them. We will assume the load-lugger truck is still required elsewhere in the plant. Pedco[21] estimates that watering the construction site will reduce emissions by 50 percent. By mixing the water and fines prior to dumping, even a greater reduction should be possible, say 85 percent. Because this vehicle will not be used except for ~1 hour a day, a used cement truck will be adequate. We will assume that a used truck can be purchased for $10,000 and will have a useful life of 5 years.

Annual Cost

Annualized capital cost	$2600
Operating cost (½ hr/day at $8/hr)	1200
Maintenance cost (3% of capital cost)	300
	$4100

Fines Control Method #6 -- Chemical Binder with Water Slurry

By using the same cement type truck as in the "Fines Control -- Water Slurry", a chemical binder could be added to the water prior to adding the fines. The net result would be a very effective way of controlling the fines emission both during the dumping operation and in the active pile.

Control of the dumping emissions will be about the same as just water, or an 85 percent reduction in emissions. Once the water evaporates off, the binder should set up the fines. The life of the binder's effectiveness

will probably vary with the level that it is used. If we assume that 50 percent of the emissions from the "active" pile originate from the baghouse fines (the other 50 percent from forming new fines from the crushing operation), then complete elimination of "baghouse" originating fines would reduce the active pile emission by 50 percent.

Preliminary indications with polyvinyl alcohol indicate that when sprayed onto the asbestos pile 8 gms/1000 cm^3 appears to be required. Assuming a bulk density of 0.6 gm/cc in the pile and assuming a penetration into the pile of 4 cm, the 8 gms/1000 cm^3 is equivalent to 0.33 wt percent concentration. If the 0.33 wt percent concentration is mixed throughout the fines, we will assume that a 90 percent reduction in emissions will be achieved (or 45 percent for the entire active pile) for the entire year. The following emission reductions from the active pile were then assumed for various concentrations of binder.

Wt % Binder Added to Fines	Active Emission Reduction
0.33	45%
0.20	37%
0.10	14%

We will assume that polyvinyl alcohol will be used as the binder at a delivered cost of $0.55/lb ($1.21/kilogram).

Wt % Binder Added to Fines	Annual Chemical Cost ($)
0.33	1,100
0.20	660
0.10	330

We will assume cement type truck can be purchased, used for $10,000 and will have a useful life of 5 years.

Annual Cost

Annualized Capital Cost	$2600
Operating Cost (3/4 hr/day at $8 hr/day)	1800
Maintenance Cost (3% of Capital)	300
	$4700

Fines Control Method #7 -- Bagging of Baghouse Fines

The bagging of the fines should be an extremely effective method of controlling both emissions at the fines dumping operation and at the active pile. Polyethylene bags, 3 mils thickness, with a capacity of 15 kg will be utilized. Because of the small number of bags to be filled each day, a manual bagging operation will be utilized. A used pick-up truck will be fitted with a bag holder so that the truck can go to each baghouse. A heat sealing iron will be located at each baghouse to rapidly seal the filled plastic bags.

Assuming a zero breakage rate of the bags during the dumping operation, the fines dumping emission should be reduced by 100 percent. These bags should easily last a full year with minimal breakage, we will assume a 10 percent breakage rate and thus an emission reduction in the active pile of 45 percent (90 percent reduction in the baghouse fines emission, the baghouse fines account for 50 percent of the emissions from the active pile). In addition, the bags will be effective in reducing the emissions from the inactive pile. Assuming that the baghouse fines account for 50 percent of the emissions from the "active" pile, the emission will be cut in half over the active pile control, or to 22 percent.

The cost of a used pick-up truck, out fitted with a bag holding device is estimated at $5,000, with an expected life of 5 years.

Annualized Capital Cost	$1300
Maintenance (2 hrs/week at $/hr)	800
Labor (2 min/bag x 60 bags)	4800
Bags ($0.20/bag x 60 bags/day)	3600
	$10,500

B -- COST ESTIMATION OF CONTROL TECHNIQUES FOR THE "ACTIVE" PILE

The active pile consists of fines from the baghouse 2 (0.9 metric tons/day), and crushed reject pipes and scraps (13.2 metric tons/day). The reject pipe is crushed monthly and then placed in the active pile. Because of space limitations, the reject pipe must be crushed to reduce the volume of water material. Four possible methods of controlling the emissions from this were evaluated.

a. Water spray

b. Foam

c. Chemical Stabilization

d. Monthly Dirt Cover over Active Pile

Control Methods #9 -- Water Spray

Water can be applied from a sprinkler system or from a tank truck equipped with a spraying system. Because the site of the active pile changes each year, it was assumed that a tank truck with a spray system will be utilized. Application of the water spray will be required 150 days per year at an application rate of 4 liters/m^2. The active pile occupies approximately 800 m^2, this 2400 liters will be required each application. A tank truck (1000 gal) can be purchased with the necessary spray system for approximately $10,000, and should have a useful life of approximately 8 years.

Based on the capital investment, the following annual cost estimate was prepared.

Annualized capital Cost (8yrs, 10%)	$1870
Labor (1 hr/day at $3/hr)	1200
Maintenance Cost (5% of Capital Investment)	500
	$3570

The efficiency of water spray systems for controlling particulate emissions was reported as "Fair" by Dean and Haven[14]. PEDCo[15] reported the following control efficiencies.

	Water Spray Control Efficiency
Construction Activities	50%
Haul Roads and Storage Areas for Aggregates	50%
Aggregate Storage	80%
Cattle Feed Lots	40%

Based on the above reported efficiencies, we will assume that water sprays would reduce asbestos emission by 50 percent.

Control Method #10 -- Chemical Stabilization

Through the use of inorganic and organic chemical binders, the control efficiency of plain water sprays can be increased. There is a wide range of chemicals that have been evaluated in the literature. Most of this literature reports the cost and application rates of the chemicals on a "per-acre" basis. Very little data on the frequency of application of the

chemicals is provided, which is required in order to do an economic evaluation. The following table summarizes the key literature:

Ref.	Chemical	Dosage Rate	Frequency of Application	Estimated Efficiency
(3)	Calcium Lingno-sulphonate and Polymer DCA-70	$335/acre	1/yr	90%
(4)	Coheres	130-1300 gm/m^2 (130 sufficient to prevent wind erosion 1300 required to prevent water erosion	--	--
(5)	Coheres	291/gm/m^2	1/week	--
(6)	Chemical Stabilization	$150-400/acre	per application	80%
(7)	Polyvinyl Alcohol	80 gm/m^2	--	--

Based upon the above summary, the following requirements were assumed for the active pile:

compound -- polyvinyl alcohol

dosage -- 100 gm/m^2

frequency -- once/month

efficiency -- 80%

We will further assume if the frequency of application is increased to once/week, the control efficiency will increase to 90 percent. The binder will be applied with the same set-up as the water spray. (Capital cost $10,000)

Dosage 1/week

Annualized Capital Cost (8 yrs, 10%)	$1870
Labor (4 hrs/application) 1/week	1600
Chemical Cost ($1.21 kilogram) applied 1/week	5000
Maintenance cost (5% of capital investment)	500
	$8970

Dosage of 1/month

Annualized Capital Cost (8 yrs, 10%)	$1870
Labor (4 hrs/application) 1/month	400
Chemical Cost ($1.21/kilogram) 1/month	1200
Maintenance Cost (5% of Capital Invest)	500
	$3970

Foam

The use of foam as a dust suppressor has been used in mining operations. Foams have been shown to be effective in reducing the dust level in the mines. The use of foams for preventing particles from becoming airborne has not been evaluated.

We can see no advantage of foaming the active pile over the use of just a chemical binder. In order to offer any advantage, the foam must be long lasting, which is not the case. Once the foam collapses, this method offers no further advantage. The foam must consist of a binder chemical plus a foaming chemical. The foam also requires more equipment than does the chemical stabilization. Then the cost of using foam will be greater than the chemical stabilization method without any increase in efficiency.

No cost estimate was prepared for foaming because it is (a) not a cost-effective method of control, and (b) one must know the life of the foam before one can estimate the cost and the effectiveness.

Control Method #11 -- Landfilling the "Active" Pile

The reject pipe is crushed once a month and then placed on the active pile. If after crushing the waste material is buried (once a month) similar to a landfill operation as shown below, an effective method of controlling emissions would be achieved.

Figure 29. Landfill operation.

The soil for a 50 cm cover could be obtained by digging a pit in front of the dump site. The dirt cover for the inactive status would still be required to insure a permanent cover.

It is estimated that the bulldozer will be used 1 week per month to compact and bury the waste asbestos material. The bulldozer will cost approximately $18,000 and will have a useful life of 8 years.

Annualized capital cost (8 yrs, 10% interest)	$3400
Maintenance (5% of capital investment)	900
Labor (40 hrs/month at $8/hr)	3800
Fuel (100 gal/month at $0.50/gal)	600
	$8700

The waste pile is only covered once per month, thus 1/12 of the uncontrolled emissions will always exist. Only a 15 cm dirt cover without vegetation or chemical stabilization is planned, thus considerable erosion will result, perhaps 20% of the uncontrolled emissions. Thus, the overall efficiency is estimated at 73 percent. In addition, there should be a slight reduction in uncontrolled emissions from the inactive pile, or perhaps a 30 percent reduction.

C -- FIELD PROCEDURES FOR SOIL EVALUATION OF STATIC TEST PILES

Test	Equipment	Field Procedure
1. Pile surface Grain size analysis	Large spoon Specimen tins Electrical tape	Collect 1 specimen from the west of each settlement plate, at the edge of the fines. Peel about ½ to 1 in. off surface; enough to fill a specimen tin. Seal with tape and identify.
2. Consolidation and surface reduction	Sight stakes (installed) Settlement plate (installed) Slide tubes (installed) Tape rule Level/angle finder	Sight across stakes to estimate drop in top of settlement plate upright rod (to nearest 1/8 in.) Measure all distances between stakes and plate rods(center to center). Measure distance from top of plate rod to top of slide. Remove slide tube and measure tilt (N-S; E-W) of upright rod to nearest ± ¼", indicate direction of tilt. Do same for sight stakes.

Test	Equipment	Field Procedure
3. Penetration resistance	Proctor Penetrometer	Use ¼"² and ½"² tips. Take 3 readings at 3 in. penetration around each settlement plate with each tip. Try to test an area not previously disturbed (record orientation and resistance).
4. Density of soil cover	Shelby tubes Wax Heater Paper Towels Masking Tape	Melt wax in can. Obtain specimens to the west of and between the settlement stakes (2 per pile). Assemble nipple and coupling to the tube with bolts supplied. Drive tube straight down with minimum tilting and no twisting until refusal (stopped). Mark depth of maximum penetration on tube. Pour ½cup wax into top of tube to seal. Withdraw tube gently (twist slightly if necessary to break at bottom). Place bottom on open paper towel which is then wrapped on tube and taped. Seal by dipping in wax, cool and dip a 2nd time. Assembly must remain upright until all wax is rigid. Identify tube.
5. Channeling	Wood Stakes (installed) Guillotine grid Camera	Measure tilt of left stake in each pair observed from perimeter of pile. Insert Guillotine into pile surface against left stake (between stake pair) until contact is made with pile across complete bottom of guillotine. Photograph close as possible for maximum detail. Identify photo.

D -- METHOD FOR CLEARING MEMBRANE FILTER

A method for clearing Millipore Type MF filters for microscopic examination was recently demonstrated. The method appears much superior to the present NIOSH method. The microscope slide specimens are permanent records which can be reexamined again at a later time. This contrasts with the present procedure which requires that the filter slide specimen be viewed immediately within a day or two of slide preparation.

The procedure is as follows:

Solutions:

Solution 1

Hexane	33% by volume
1,2 dichloroethane	33% by volume
p-dioxane	33% by volume

Solution 2

Acetone	100% by volume

Method:

1. Flood a clean slide with Solution 1.
2. With forceps, roll a pie-shaped wedge of the test filter, particle side up, onto the glass slide to thoroughly wet it (about two seconds).
3. Immediately roll the wet filter onto a second clean, dry slide, particle side up.
4. Invert the slide over a shallow dish of acetone. The filter will clear in about one minute.
5. Place a coverglass over cleared specimen and count.

A thin film is created from the membrane in this process. Air is displaced and the filter membrane material (porous structure of mixed cellulose esters) is wetted by the first solution. Then exposure to the acetone vapors quickly dissolves and collapses the porous filter structure (70% voids). The aerosol particles collected on the filter are originally trapped on or near the top surface of the membrane filter. When the membrane structure is collapsed, the particles align themselves in the plane of the film surface. This places all of the particles in much sharper focus than before under the microscope. After the solvent evaporates, the film remains clear and stable and slide can be retained as a record for future reference.

E — LISTING ANALYSES OF HIGH VOLUME AIR SAMPLES

Experiment		Filter	Sample		Sampling Time, min.	Wind		Weather	Stability Class	Service Concentration		
										Alpha Activity Dpm/m³ × 10⁻³	Beta Activity Dpm/m³ × 10⁻³	Gamma Activity Dpm/m³ × 10⁻³
No.	Date	No.	No.[1]	Activity		Direction	Speed[2]					
1	[illegible]	1	1	Area Background	115	E	14.2	Clear, hot	A	0.87	3.2	
1	[illegible]	2	2	Area Background	122	S-SE	14.2	Clear, hot	A	1.06	3.7	
1	[illegible]	3	3	Area Background	122	N	14.2	Clear, hot	A	1.21	3.0	
1	[illegible]	4	4	Area Background	120	N	14.2	Clear, hot	A	1.34	2.4	
1	[illegible]	5	5	Area Background	108	Still air	14.2	Clear, hot	A	1.34	2.8	
1	[illegible]	10	6	Area Background	114	Still air	14.2	Clear, hot	A	0.77	1.3	
2	[illegible]	1	1	Area Background	120	Still air	14.2	Sunny, hot	A	0.88	1.5	
2	[illegible]	6	2	Area Background	120	Still air	14.2	Sunny, hot	A	1.30	1.8	
2	[illegible]	7	3	Area Background	120	Still air	14.2	Sunny, hot	A	3.42	5.3	1.2
2	[illegible]	8	4	Area Background	120	Still air	14.2	Sunny, hot	A	0.83	1.1	
2	[illegible]	11	5	Area Background	120	Still air	14.2	Sunny, hot	A	0.88	.96	
2	[illegible]	12	6	Area Background	120	Still air	14.2	Sunny, hot	A	0.90	1.06	
3	[illegible]	13	7	Test Pile 1	120	S	9-12.6	Clear, hot	A	1.31		
3	[illegible]	14	8	Test Pile 1	120	S	9-12.6	Clear, hot	A	1.23		
4	[illegible]	20	11	Area Background	113	S-SE	5.3	Clear, hot	C	0.46		
4	[illegible]	21	24	Area Background	12	S-SE	5.3	Clear, hot	C	0.03		
4	[illegible]	22	4	Area Background	96	S-SE	5.3	Clear, hot	C	0.39		
7	[illegible]	23	7	Test Pile (Fresh)	125	S	9-6.6	[illegible]	D	0.52	0.24	
7	[illegible]	24	8	Test Pile (Fresh)	122	S	9-6.6	[illegible]	D	0.39	0.20	
7	[illegible]	25	9	Test Pile (Fresh)	118	S	9-6.6	[illegible]	D	0.46	0.11	
7	[illegible]	26	10	Test Pile (Fresh)	116	S	9-6.6	[illegible]	D	0.61	0.19	
7	[illegible]	27	11	Test Pile (Fresh)	46	S	9-6.6	[illegible]	D	0.47		
7	[illegible]	28	12	Test Pile (Fresh)	120	S	9-6.6	[illegible]	D	0.49	0.24	
10	[illegible]	41	11	Dam Background	123	S-SE	3.9-5.3	Lt. overcast	B-C	0.19		
10	[illegible]	42	25	Dam Background	127	S-SE	3.9-5.3	Lt. overcast	B-C	0.71		
10	[illegible]	43	24	Dam Background	123	S-SE	3.9-5.3	Lt. overcast	B-C	1.20		
11,12	[illegible]	34	31	Crushing at Dam	120	SE-SW	1.3-4.6	Mostly sunny	C	0.57	3.3	
11	[illegible]	42	32	Crushing at Dam	5	SE-SW	1.3-4.6	Mostly sunny	C	BL	BL	

[1] See Figures 10, 11, 16, and 17.
[2] Wind speed at 10 m height, m/sec.

E — (continued)

Experiment		Filter No.	Sample No.[a]	Activity	Sampling Time, min.	Wind		Weather	Stability Class	Direct Concentration		
No.	Date					Direction	Speed[b]			Gamma Absorption Eqn. (g/m³) × 10⁻⁶	Optical Attenuation Eqn. (Filter Length 5 μm) (g/m³) × 10⁻⁶	Electron Attenuation Eqn. (g/m³) × 10⁻⁶
12	09-10-55	46	23	Crushing at Site	29	SE-Sw	1.3-4.5	Mostly sunny	C	6.8	16.	
12	09-10-55	47	24	Crushing at Site	30	SE-Sw	1.3-4.5	Mostly sunny	C	23.6		
13	09-10-55	48	25	Crushing at Site	15	SE-Sw	1.3-4.5	Mostly sunny	C	22.6		
13	09-10-55	49	25	Crushing at Site	15	SE-Sw	1.3-4.5	Mostly sunny	C	19.4		
13	09-10-55	50	26	Crushing at Site	15	SE-Sw	1.3-4.5	Mostly sunny	C	19.4		
13	09-10-55	51	27	Crushing at Site	15	SE-Sw	1.3-4.5	Mostly sunny	C	21.8	35.	22.3
13	09-10-55	52	28	Crushing at Site	15	SE-Sw	1.3-4.5	Mostly sunny	C	14.5		
13, 14, 15	09-10-55	53	29	Crushing at Site	15	SE-Sw	1.3-4.5	Mostly sunny	C	10.8		
14	09-10-55	54	30	Crushing at Site	142	SE-Sw	1.3-4.5	Mostly sunny	C	0.48		
14	09-10-55	55	31	Crushing at Site	35	SE-S	1.3-4.5	[illegible]	C	46.6		
14	09-10-55	56	32	Crushing at Site	39	SE-S	1.3-4.5	[illegible]	C	39.9		
15	09-10-55	57	33	Crushing at Site	47	SE-S	1.3-4.5	[illegible]	C	28.2		
15	09-10-55	58	34	Crushing at Site	25	SE-S	1.3-4.5	[illegible]	C	62.4		
15	09-10-55	59	35	Crushing at Site	29	SE-S	1.3-4.5	[illegible]	C	12.5		
15	09-10-55	60	36	Crushing at Site	29	SE-S	1.3-4.5	[illegible]	C	3.7		
15	09-10-55	61	37	Crushing at Site	37	SE-S	1.3-4.5	[illegible]	C	4.1		
16	09-11-55	62	38	Water only	33	S-Sw	3.5-6.5	Clear, Dark	C	7.9		
17	09-11-55	64	39	Site Background	32	S-Sw	3.5-6.5	Clear, Dark	C	4.5	6.4	
17	09-11-55	65	40	Site Background	39	S-Sw	3.5-6.5	Clear, Dark	C	11.4		
17, 18	09-11-55	66	41	Site Background	<90	S-Sw	3.5-6.5	Clear, Dark	C	1.28		
17	09-11-55	67	42	Site Background	35	S-Sw	3.5-6.5	Clear, Dark	C	3.20		
17	09-11-55	68	43	Site Background	67	S-Sw	3.5-6.5	Clear, Dark	C	6.2	5.7	2.1
17	09-11-55	69	44	Site Background	69	S-Sw	3.5-6.5	Clear, Dark	C	1.40		
18	09-11-55	71	22	Leveling and Fines at Site	<30	S-Sw	0-7.5	Clear, Dark	C	0.6		
18	09-11-55	72	24	Leveling and Fines at Site	32	S-Sw	0-7.5	Clear, Dark	C	46.3	30.	10.0
18	09-11-55	73	25	Leveling and Fines at Site	32	S-Sw	0-7.5	Clear, Dark	C	15.7		
18	09-11-55	74	27	Leveling and Fines at Site	32	S-Sw	0-7.5	Clear, Dark	C	12.6		

[a] See Figures 10, 11, 16, and 17.
[b] Wind speed at 10 m height, mph.
[c] Shut off before end of test.

E — (continued)

Experiment		Flight	Sample		Sampling Time, min	Wind		Weather	Sampling Class	Sample Concentration		
No.	Date	No.	No.[1]	Activity		Direction	Speed[2]			Atom Aerosol Mass, mg/m³ × 10⁻¹	Sample Aerosol Mass, Fiber Length > 5 μ, mg/m³ × 10⁻¹	Electron Aerosol Mass, Fiber Length > 5 μ, mg/m³ × 10⁻¹
14	29-11-75	15	20	Leveling at [illegible] and Fixes	30	S-SW	0-1.5	Clear, hot	C	15.3	25.	15.2
15	29-11-75	16	22	Leveling at [illegible] Fixes	15	SW	4.5-5.3	Clear, hot	C	4.46		
16	29-11-75	17	23	Leveling at [illegible] Fixes	15	SW	4.5-5.3	Clear, hot	C	39.4		
17	29-11-75	18	24	Leveling at [illegible] Fixes	15	SW	4.5-5.3	Clear, hot	C	223.		
18	29-11-75	19	25	Leveling at [illegible] Fixes	15	SW	4.5-5.3	Clear, hot	C	5.88		
19	29-11-75	20	31	Leveling at [illegible] Fixes	120	SW	4.5-5.3	Clear, hot	C	2.44		
20	29-11-75	21	32	Leveling at [illegible] Fixes	15	SW	4.5-5.3	Clear, hot	C	34.0		
21	29-11-75	22	29	Area Background, Fisher, W.	125	S	3.5-5.3	Warm, hot	C	0.11	1.12	
22	29-11-75	23	30	Area Background, Dobson Co., N.D.	125	S	3.5-5.2	Warm, hot	C	0.0	1.37	
23	10-12-75	112	1	Test Fire	115	S	6.5	Clear, dry	C	0.19	0.58	
24	10-12-75	114	5	Test Fire	115	S	6.5	Clear, dry	C	0.61	1.00	
25	10-12-75	116	7	Test Fire	120	S	6.5	Clear, dry	C	0.46	0.56	
26	10-12-75	117	8	Test Fire	115	S	6.5	Clear, dry	C	0.48	1.30	
27	10-12-75	118	10	Test Fire	115	S	6.5	Clear, dry	C	0.35	0.40	
28	10-12-75	119	12	Test Fire	111	S	6.5	Clear, dry	C	0.33	0.80	
29	10-24-75	107	11	Test Fire	120	S-SE	5.0	Warm, dry	C	0.54		
30	10-24-75	108	1	Test Fire	120	S-SE	5.0	Warm, dry	C	0.75		
31	10-24-75	109	7	Test Fire	120	S-SE	5.0	Warm, dry	C	0.74		
32	10-24-75	110	8	Test Fire	120	S-SE	5.0	Warm, dry	C	0.86		
33	10-24-75	111	10	Test Fire	115	S-SE	5.0	Warm, dry	C	0.66		

[1] See Figures 10, 11, 36, and 37.
[2] Wind speed at 72 m height, mps.

E — (Continued)

Experiment		Flight No.	Test Log No.[1]	Activity	Testing Time, min	Wind		Weather	Instrument Class	Device Characteristics		
No.	Date					Direction	Speed[2]			Static Absorption Sig, $(kg/m^2) \times 10^{-3}$	Period Summation Sig, $(T_{eff}/T_{amb})^2 \times 10^{-4}$	Electron Absorption Sig, $(Coulomb/m^2) \times 10^{-10}$
27	10-24-55	133	12	Test Flite	114	S-SE	5.8	[illegible]	C	0.35		
28	10-27-55	140	11	Test Flite	108	S-SE	7.2	[illegible]	C	0.37	0.42	
29	10-27-55	141	9	Test Flite	103	S-SE	7.2	[illegible]	C	0.35		
30	10-27-55	142	7	Test Flite	101	S-SE	7.2	[illegible]	C	0.39	0.60	
31	10-27-55	144	8	Test Flite	100	S-SE	7.2	[illegible]	C	0.46	0.67	
32	10-27-55	145	10	Test Flite	100	S-SE	7.2	[illegible]	C	0.59	0.65	
33	10-27-55	146	12	Test Flite	119	S-SE	7.2	[illegible]	C	0.53	0.61	
34	10-27-55	147	11	Test Flite	102	S-SW	7.9	[illegible]	C	0.37		
35	10-31-55	159	9	Test Flite	109	S-SW	7.9	[illegible]	C	0.33		
36	10-31-55	159	7	Test Flite	109	S-SW	7.9	[illegible]	C	0.55		
37	10-31-55	160	8	Test Flite	110	S-SW	7.9	[illegible]	C	0.56		
38	10-31-55	161	10	Test Flite	117	S-SW	7.9	[illegible]	C	0.74		
39	10-31-55	162	12	Test Flite	11[illegible]	S-SW	7.9	[illegible]	C	0.35		
40	11-02-55	170	11	Test Flite	107	S-SW	6.6	[illegible]	D	0.85		
41	11-02-55	172	9	Test Flite	105	S-SW	6.6	[illegible]	D	0.68		
42	11-02-55	173	7[a]	Test Flite	—	S-SW	6.6	[illegible]	D	—		
43	11-02-55	174	12	Test Flite	108	S-SW	6.6	[illegible]	D	0.37		
44	11-02-55	175	10	Test Flite	110	S-SW	6.6	[illegible]	D	0.37		
45	11-02-55	176	8	Test Flite	110	S-SW	6.6	[illegible]	D	2.74		
46	11-04-55	187	11	Test Flite	107	S-SW	5.3–10.5	[illegible]	D	0.33		
47	11-04-55	188	9	Test Flite	105	S-SW	5.3–10.5	[illegible]	D	0.47		
48	11-04-55	189	7	Test Flite	107	S-SW	5.3–10.5	[illegible]	D	0.46		
49	11-04-55	190	8	Test Flite	107	S-SW	5.3–10.5	[illegible]	D	0.59		
50	11-04-55	191	10	Test Flite	105	S-SW	5.3–10.5	[illegible]	D	0.77		
51	11-04-55	192	12	Test Flite	111	S-SW	5.3–10.5	[illegible]	D	0.32		

[1] See Figures 10, 11, 15, and 12.
[2] Wind speed at 12 m height, knots.
[a] Invalid (flight over).
[b] Invalid (not operating).

F — EMISSION CONTROL COST OPTIONS FOR COMPLETE CONTROL OPTIONS (INCLUDING ANNUAL INACTIVE PILE)

Emission Inventory, kg/hr	
Active Dump	0.090
Crushing	0.009
Flows Dumping	0.054
Inactive Pile	0.010
	0.151

Control Methods	Capital Invest. ($)	Total Annual Cost	% Reduction in Emissions From: Flows Dumping	Aggregate Crushing	Active Pile	Inactive Pile	Total Reduction
1. Water Spray + Flows Dumping	3,700	2,800	10	—	—	—	2
2. Water + Surfactant + Flows Dumping	4,000	3,400	20	—	—	—	4
3. Agglomeration of Flows with Water	25,000	10,000	90	—	5	—	23
4. Agglomeration of Flows with Binder	25,000	13,000	90	—	25	—	35
5. Water Slurrying of Flows	10,000	4,100	85	—	—	—	19
6a. Chemical Binder with Water Slurry @ 0.25% Binder	10,000	5,000	85	—	45	—	40
6b. Chemical Binder with Water Slurry @ 0.20% Binder	10,000	5,400	85	—	27	—	35
6c. Chemical Binder with Water Slurry @ 0.10% Binder	5,000	5,000	65	—	36	—	27

F — (continued)

Control Methods	Capital Invest ($)	Total Annual Cost	% Reduction in Emissions From: Fines Dumping	Aggregate Crushing	Active Pile	Inactive Pile	Total Emissions
7. Bagging of Baghouse Fines	5,000	10,500	100	—	45	22	52
8. Chemical-Vegetative Control of Inactive Fines	—	3,380	—	—	—	100	12
8+1.	3,700	6,180	20	—	—	100	14
8+2.	4,000	3,780	20	—	—	100	16
8+3.	25,000	13,380	90	—	5	100	35
8+4.	25,000	16,380	90	—	25	100	47
8+5.	10,000	7,480	85	—	45	100	31
8+6a.	10,000	9,180	85	—	45	100	58
8+6b.	10,000	8,780	85	—	27	100	47
8+6c.	10,000	8,380	85	—	14	100	39
8+7.	5,000	13,800	85	—	45	100	62
9. Water Spray on Active Pile	10,000	3,570	—	—	90	—	30
10a. Chemical Stabilize Active Pile 1/wk	10,000	8,970	—	—	90	—	54
10b. Chemical Stabilize Active Pile 1/month	10,000	3,970	—	—	80	—	48
11. Landfilling the Active Pile 1/month	10,000	6,700	—	—	73	20	46
8+9.	10,000	6,950	—	—	50	100	42
8+10a.	10,000	12,330	—	—	90	100	59

F — (continued)

Control Methods	Capital Invest ($)	Total Annual Cost	% Reduction in Emissions From: Fines Dumping	Aggregate Crushing	Active Pile	Inactive Pile	Total Emissions
9+10b. Landfilling the Active Pile 1/month	10,000	7,350	—	—	80	100	59
9+11.	10,000	12,065	—	—	73	100	55
9+6a+10b.	20,000	11,150	85	—	69	100	94
9+6a+10a.	20,000	10,130	85	—	94	150	57
9+5+10b.	20,000	11,450	85	—	60	100	79
9+7+10b.	15,000	17,850	100	—	89	100	60
9+5+9.	20,000	11,050	85	—	50	150	61
9+6a+9.	20,000	12,750	85	—	72	100	74
9+6b+9.	20,000	12,350	85	—	64	100	69
9+6a+10b.	20,000	12,750	85	—	85	100	82

SECTION 9

REFERENCES

1. G.F. Harwood, P. Ase, and M. Stinson, "Study of the Effect of Asbestos Waste Piles on Ambient Air", in Proc of Symposium on Fugitive Emissions Measurement and Control, U.S. EPA Report No. 600/2-76-246, September, 1976.

2. P.G. Pigott, E.G. Valdez, and E.C. Dean, "Steam Cured Bricks from Industrial Mineral Wastes", Rept. of Investigations 7856, Bureau of Mines (1974). TN 23 U7, No. 7856.

3. H.F. W. Taylor, ed., The Chemistry of Cements, Vol 1, Academic Press, N.Y., p. 430 (1964)

4. R.H. Snow, et al., "Size Reduction and Size Enlargement", in Chemical Engineers' Handbook, R.H. Perry and C.H. Chilton, ed., McGraw Hill Book Co., N.Y. (1974)

5. Browning, Chemical Engineering, 74, (25) 147 (1967)

6. U.S. Bureau of Mines, Contract No. H0110929, March 1972, Coal Age, 76 96, July 1971.

7. J.H. Hoover and D.T. Davidson, "Preliminary Evaluation of Some Organic Cationic Chemicals as Stabilizing Agents for Iowa Loess", Iowa State University Bull., #22, 31 (1960)

8. F.G. Kardoush, et al., "Stabilization of Loess with a Promising Quaternary Ammonium Chloride" Iowa State University Bull., #22, 54 (1960)

9. D.T. Davidson, "Exploratory Evaluation of Some Organic Cations as Soil Stabilizing Agents", Iowa State University Bull., #22, 1 (1960)

10. W.W. Emerson, "Synthetic Soil Conditioners", J. Agric. Sci., 47, 117 (1956)

11. F.J. Blavia, W. Heidenhauer, and D.E. Law, "Materials for Stabilizing Surface Clods of Soils", Soil Sci. Amer. Proc., (1) 119 (1971).

12. G.B. Wells, "Resin Impregnation of Soil Samples", Nature, 193 (4817) 804 (1962).

13. H.J. Fielder and P. Czerney, "Soil Stabilization with Artificial Resins" Z. Landwirtsch, Versuchs. - Untersuchungsw., 9 (4) 437 (1963)

14. R.G. Stefanson, "PVA as Stabilizer for Surface Soils", Soil Sci., 115 (6) 420 (1973).

15. R.G. Stefanson, "Soil Stabilization by PVA and its Effect on the Growth of Wheat", Aust. J. Soil Res., 12, 59 (1974).

16. J.P. Voets, et al., "Microbiological and Biochemical Effects of Application of Bituminous Emulsions", Plant and Soil, 39, 433, (1973).

17. W.A. Berg, "Vegetative Stabilization of Mine Waters", Proc. Critical Area Stabilization Workshop, Ag. Res. Service USDA, Las Cruces, N.M. (1973).

18. K.C. Dean, and R. Haven, "Reclamation of Mineral Milling Wastes" in Proc. of the Third Mineral Waste Utilization Symposium at IIT Research Institute, March 14-16, 1972.

19. R.G. Haeuwig, "Infiltration and Soil Erosion as Influenced by Vegetation and Soil in Northern Utah", J. Range Mgt., 23, 185 (1970)

20. H.P. Woodruff and F.H. Siddoway, "A Wind Erosion Equation", Soil Sci. Proceedings, 29, 602-608, (1965).

21. C.F. Harwood and T.P. Balcomb, "Characterization and Control of Asbestos Emissions from Open Sources", U.S. EPA Report No. 650/2-74-090 September 1974.

22. D.B. Turner, Workbook of Atmospheric Dispersion Estimates, U.S.P.H.S. Publ. No. 999-AP-26 (1970).

23. PEDCo Environmental Specialists, Inc., Investigation of Fugitive Dust Sources, Emissions and Control, U.S. EPA Report No. APTD-1582, May 1973.

24. The COHEREX Manual for Dust Control, Witco Chemical Corp., Golden Bear Div., Bakersfield, CA (1970).

25. R.P. Beasley, Erosion and Sediment Pollution Control, Iowa State University Press, Ames, Iowa (1972).

26. Joint AIHA-ACGIH Aerosol Hazards Evaluation Committee "Recommended Procedures for Sampling and Counting Asbestos Fibers", AIHAJ, 36 83-90 (Feb. 1975).

27. Methods for Chemical Analysis of Water and Wastes, U.S. EPA, Cincinnati Ohio, Analytical Quality Control Laboratory, EPA-625-26-74-003, p.82 (1974).

28. Perkin-Elmer, "Analytical Methods for Atomic Absorption Spectrophotometry", (March 1973).

29. A.D. Busse and J.R. Zimmerman, "User's Guide for the Climatological Dispersion Model", National Environmental Research Center, U.S. EPA Research Triangle Park, N.C. 27711, EPA-RA-73-024 (December 1973).

30. J.A. Danielson, Air Pollution Engineering Manual, U.S. EPA Publication AP-40, 100 (1973).

31. E.W. Hoof and J.W. MacDonald, "Economic Evaluation of Wet Scrubbers", CEP, 71 (3) 49 (March 1975).

32. E. Knutson, IITRI Final Report No. C6105-28 (1974).

33. Anonymous, "How a Combination of Water and a Surfactant Can Solve Air Pollution Problems", Minerals Processing (May 1972).

34. Ferro-Tech Incorporated, Data Sheet FT-204B.

35. P.R. Vallee and H. Wagner, "Agglomeration System Tames Hazardous Dust", Chemical Processing, 39 (9) 30 (1976).